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TEMTADS Adjunct Sensor Systems

Hand-held EMI Sensor for Cued UXO Discrimination (ESTCP MR-200807) and Man-Portable EMI Array for UXO Detection and Discrimination (ESTCP MR-200909) Final Report

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14. ABSTRACT
Man-portable (MP) and Hand-held (HH) adjuncts of the NRL TEMTADS 5×5 array were constructed and the UXO classification performance of each characterized. Both systems are based on the transient electromagnetic induction (TEM) sensor technology that was developed for the NRL TEMTADS 5×5 array. Both systems are designed to be deployable in increasingly inaccessible areas where vehicle-towed sensor arrays cannot be used. Demonstration results for the MP system indicated that the performance of the system was not comparable to that of the full TEMTADS 5×5 array. A modified version of the EMI sensors in the MP system was designed and built, replacing the single, vertical-axes receiver loops of the original coils with three-axis receiver cubes. The HH sensor was designed for use in extremely limiting terrain and for integration with unique positioning technologies. The demonstration results for the HH sensor indicated that the performance of the system was comparable to that of the full TEMTADS 5×5 array.

15. SUBJECT TERMS

Discrimination	Multi-sensor Towed Array Detection System (MTADS)	TEMTADS
Classification	Electromagnetic induction (EMI)	Hand-held
Unexploded ordnance (UXO)	Transient electromagnetic induction (TEM)	Man-portable

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Acronyms

Abbreviation	Definition
AOL	Advanced Ordnance Locator
APG	Aberdeen Proving Ground
ATC	Aberdeen Test Center
AUES	American University Experimental Station
CRREL	Cold Regions Research and Engineering Laboratory
EMI	Electro-Magnetic Induction
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
HH	Hand-held
Hz	Hertz
INS	Inertial Navigation System
IVS	Instrument Verification Strip
MP	Man-Portable
MR	Munitions Response
MTADS	Multi-sensor Towed Array Detection System
NRL	Naval Research Laboratory
PDA	Personal Data Assistant
POC	Point of Contact
QC	Quality Control
RMS	Root-Mean-Squared
RTK	Real Time Kinematic
Rx	Receiver
SAIC	Science Applications International Corporation
SAINT	Small-Area Inertial Navigation Tracking (unit)
SLO	San Luis Obispo
SNR	Signal-to-Noise Ratio
TEM	Time-domain Electro-Magnetic
TEMTADS	Time-domain Electro-Magnetic MTADS
Tx	Transmit(ter)
USACE	U.S. Army Corps of Engineers
UXO	Unexploded Ordnance

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This work was done as part of the Naval Research Laboratory's ESTCP-funded projects MR-200807 and MR-200909. The work was done in collaboration with Nova Research, Science Applications International Corporation (SAIC), and G&G Sciences. Dave George of G&G Sciences was responsible for the development of the EMI sensor technology on which the TEMTADS arrays are built. Tom Bell of SAIC, Dan Steinhurst and Glenn Harbaugh of Nova Research, and Barry Mathieu of Berry Design, collaborated on the design of the integrated MP cart and hand-held sensor system. Dan Steinhurst and Barry Mathieu were responsible for the design and construction of back-pack mountable electronics package for the sensor systems. Jim Kingdon, Bruce Barrow, Jonathan Miller, and Dean Keiswetter of SAIC were also involved in the modeling/analysis of the resultant data.

We would like to thank Rick Fling of the Aberdeen Test Center for his invaluable assistance with both demonstrations at the APG Standardized UXO Test Site. The authors would also like to thank Brian Ambrose of DuPont for providing access to the Remington Woods, CT site as part of their ongoing remediation efforts and to Jeffrey Kronick of URS Corporation for onsite support at the Remington Woods Site. Andrew Schwartz of the U.S. Army Corps of Engineers, Huntsville provided the funding for the Dalecarlia Woods, Washington, DC site under the USACoE Innovative Technology Program. The USACE Baltimore District and the Shaw Group provided site access and support for the Dalecarlia Woods, Washington, DC site.

EXECUTIVE SUMMARY

The performance of man-portable and hand-held configurations of the Naval Research Laboratory TEMTADS sensor are presented. Both systems are based on the transient electromagnetic induction (TEM) sensor technology that was developed under Environmental Security Technology Certification Program project MR-200601, "EMI Array for Cued UXO Discrimination," or the TEMTADS 5x5 array. The man-portable (MP) system was constructed as a 2x2 array of the sensors developed for the original TEMTADS. For the hand-held (HH) sensor, a single, coaxial Tx/Rx coil pair was developed to capture the performance of the original sensor while made rugged enough for handheld use in the field. The required data diversity for the HH sensor comes from making a series of 40 measurements over the target using a physical template for precise relative geolocation. Both systems are designed to be deployable in increasingly inaccessible areas where vehicle-towed sensor arrays cannot be used.

Demonstrations of these systems have been conducted at our test facility at Blossom Point, MD, at the UXO Standardized Test Site at Aberdeen Proving Ground, and at live sites in Bridgeport, CT and Washington, DC. These sites offer a range of UXO sizes and types along with a selection of munitions-related scrap and cultural clutter. The results of these demonstrations are discussed in terms of classification performance and production rate.

For the MP system, the APG results indicated that the inversion performance of the system was not comparable to that of the full TEMTADS 5x5 array for lower SNR targets due to the limits of the smaller data set (fewer looks at the target). The results of the live site demonstrations supported the conclusions drawn after the APG demonstration.

Revision of the sensor technology was indicated for the MP system to collect sufficient data over an anomaly. A modified version of the EMI sensors in the MP system was designed and built, replacing the single, vertical-axes receiver loops of the original coils with three-axis receiver cubes. The new sensor elements were designed to have the same form factor as the originals, aiding in system fabrication.

The HH sensor was designed for use in extremely limiting terrain and for integration with unique positioning technologies. The APG results for the HH sensor indicated that the inversion performance of the system using a 36-point observation grid was comparable to that of the full TEMTADS 5x5 array.

The primary performance comparisons are referenced against the performance of the original TEMTADS 5x5 array.

1.0 INTRODUCTION

1.1 BACKGROUND

Unexploded ordnance (UXO) contamination at former and current Department of Defense sites is an extensive problem. Site characterization and remediation activities conducted with the current state-of-the-art technologies at these sites often yield unsatisfactory results and are extremely expensive to implement. This is due in part to the inability of current technology to distinguish between UXO and nonhazardous items. Newly-emerging electromagnetic induction (EMI) sensor technologies offer the ability to robustly distinguish between these two classes of objects. Early versions of these systems have tended to be large and designed for towed operation on open fields with good sky view to provide the necessary quality of geolocation information. The objective of Environmental Security Technology Certification Program (ESTCP) projects MR-200807 and MR-200909 is to demonstrate sensor arrays that are capable of reliably retaining the performance of one of these new technologies in a form suitable for use in rugged terrain and other environments where mobility and the viability of traditional positioning technologies are limited. The systems demonstrated in both projects are based on the transient electromagnetic induction (TEM) sensor technology that was developed under ESTCP project MR-200601.

1.2 OBJECTIVES OF THE PROJECTS

The objective of these ESTCP-funded Naval Research Laboratory (NRL) projects was to validate new UXO classification technologies through a series of blind test demonstrations. We have conducted frequent shake-down demonstrations of each technology at our Blossom Point, MD field site but a blind test is the only true measure of system performance. Both sensor technologies were demonstrated at the Aberdeen Proving Ground (APG) Standardized UXO Test Site. The TEMTADS MP 2x2 Cart (MP system) was also demonstrated at the DuPont Remington Woods, CT site several times during development as part of an ongoing classification-based UXO remediation effort. The MP system array conducted a brief, exploratory demonstration at the Dalecarlia Woods site in Spring Valley, Washington, DC with sponsorship from the U.S. Army Corps of Engineers (USACE), Huntsville through their Innovative Technologies Program.

1.3 REGULATORY DRIVERS

Stakeholder acceptance of the use of classification techniques on real sites will require demonstration that these techniques can be deployed efficiently and with high probability of discrimination. The first step in this process is to demonstrate acceptable performance on synthetic test sites such as that at Aberdeen. As a second step, demonstration in more real-world scenarios is required. Further demonstration at live sites with more extensive ground-truth validation will further facilitate regulatory acceptance of the UXO classification technology and methodology.

Manuscript approved January 27, 2012.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 EMI Sensors

Two types of sensors are discussed in this report. The first is the EMI sensor developed for the NRL TEMTADS 5x5 array under ESTCP project MR-200601 and described in the next paragraph, consisting of a single 35 cm x 35cm transmitter loop coaxially located with a single 25 cm x 25cm vertical-axis receiver loop. The second is the 'TEMTADS/3D' sensor in which the same transmitter coil is used but the receiver coil is replaced by an 8 cm, 3-component 'cube' receiver that was first developed by G&G Sciences under a Navy-funded project known as the Advanced Ordnance Locator (AOL). We have adopted systems made from multiple copies of these sensors, assembled in a variety of array configurations. We also made minor modifications to the control and data acquisition computer to make it compatible with our deployment schemes.

A photograph of a standard TEMTADS sensor element (as used in the MR-200601 array) is shown under construction in the left panel of Figure 2-1. The Tx coil is wound around the outer portion of the form and measures 35 cm on a side. The 25 cm x 25 cm, square Rx coil is wound around the inner part of the form which is re-inserted into the outer portion with the Rx coil in place. An assembled sensor with the top and bottom caps used to locate the sensor in the array is shown in the right panel of Figure 2-1.

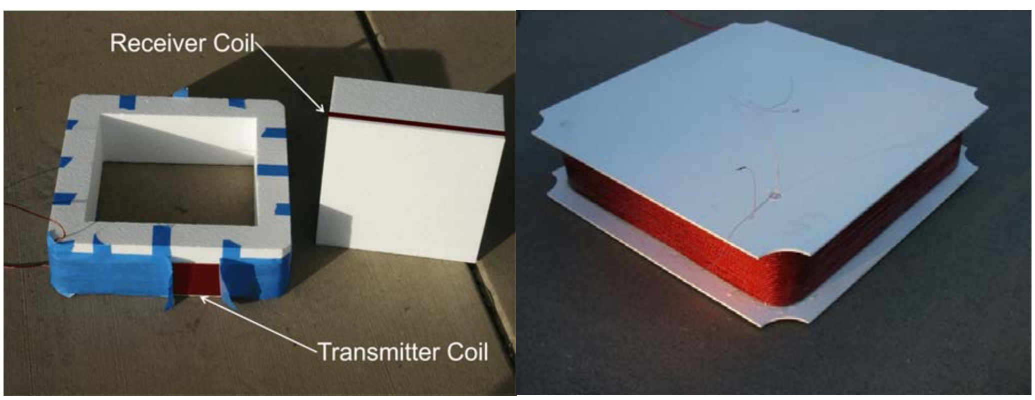


Figure 2-1 – Construction details of an individual standard TEMTADS EMI sensor (left panel) and the assembled sensor with end caps attached (right panel).

Decay data are collected with a 500 kHz sample rate until 25 ms after turn off of the excitation pulse. A raw decay consists of 12,500 points; too many to be used practically. These raw decay measurements are grouped into 122 logarithmically-spaced "gates" with center times ranging from 25 μs to 24.375 ms with 5% widths and the binned values are saved to disk.

2.1.2 TEMTADS Hand-Held EMI Sensor

For the TEMTADS Hand-Held sensor (HH sensor), a new configuration of the TEMTADS EMI sensor was developed that is rugged, weather-proof, and designed with the needs of a handheld instrument in mind. The sensor includes a 35-cm diameter Tx coil and an inner, 25-cm diameter Rx coil. The assembled coil is significantly thinner than the TEMTADS sensor (2 vs. 8 cm) and is designed with a clear center aperture which can be fitted with a variety of alignment fixtures. Shown in Figure 2-2 is a simple cross-hair arrangement made from clear acrylic.

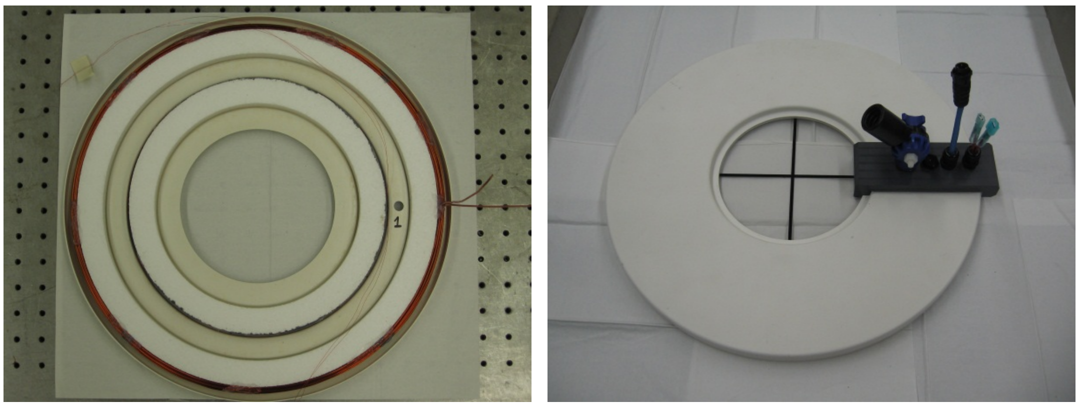


Figure 2-2 – Construction details of the TEMTADS Hand-Held Sensor (left panel) and the assembled sensor (right panel).

2.1.3 EMI Sensor with Tri-axial Receiver Cubes

As will be discussed further in Section 7.8, after demonstration of the MP system at the APG Standardized UXO Test Site in August, 2010 [1], revision of the sensor technology was indicated for the MP system to collect sufficient data over an anomaly. A modified version of the sensor element was designed and built, replacing the single, vertical-axis receiver coil of the original sensor with a three-axis receiver cube. These receiver cubes are similar in design to those used in the second-generation AOL and the Geometrics MetalMapper (ESTCP MR-200603) system with dimensions of 8 cm rather than 10 cm. The CRREL MPV2 system (ESTCP MR-201005) uses an array of five identical receiver cubes and a circular transmitter coil. The new sensor elements are designed to have the same form factor as the originals, aiding in system integration. A new coil under construction is shown in Figure 2-3.

Figure 2-3 – Individual updated TEMTADS EMI sensor with 3-axis receiver under construction.

2.1.4 Application of the Technology

Application of this technology is evaluated for 'cued-target classification.' In this application, targets have been previously detected and a list of target positions is developed from a survey by some other geophysical instrument; for example an EM61-MK2 cart survey. Each target location is marked in advance with a non-metallic pin flag or similar item and preferably labeled with the target ID number. The operator positions either the MP system or a wooden template for the HH sensor over each target in turn. Once positioned over the target, data acquisition is conducted. For the HH, a monostatic measurement is made at each marked position along a 6x6 template along with a series of background measurements. For the MP array, the data acquisition computer steps through the array sensors sequentially, collecting decays from all twelve receive coils for each excitation. These data are then inverted for target location and characteristics.

In the final version of this technology, one could envision the inversion being performed on-the-fly prior to or while the operator moves to the next target. For these demonstrations, we performed the inversions off-line so that we would have the ability to intervene in the automatic process as required. The TEM data were transferred to the analyst several times each day for near real-time analysis at the demonstration site.

2.2 TECHNOLOGY DEVELOPMENT

The MP system is a man-portable four-element transient EMI system designed and built by the NRL with funding from ESTCP, to transition the TEM sensor technology of the TEMTADS towed array (ESTCP Project MR-200601) to a more compact, man-portable configuration for use in more limiting terrain under project MR-200909. Like the towed array, this system is currently configured to operate in a cued mode, where the target location is already known. The MP system is shown in Figure 2-4.

Figure 2-4 – The NRL TEMTADS MP 2x2 Cart

Preliminary testing of the initial system configuration [2] found that for high SNR (≥ 30) targets one measurement cycle provides enough information to support classification. For deeper and/or weaker targets, more robust estimates of target parameters are obtained by combining two closely-spaced measurements. Two measurements per anomaly were typically made proactively to avoid the potential need to revisit a target a second time [2]. As part of project MR-200909, a demonstration was conducted to rigorously investigate the capabilities of this new sensor platform for UXO classification in a cued data collection mode at the APG Standardized UXO Test Site in August, 2010. The results are presented in Section 7.0. Those results indicated that the inversion performance of the system was not comparable to that of the full TEMTADS array for lower SNR targets due to the limits of the smaller data set (fewer looks at the target).

Several additional data collection windows of opportunities were available prior to the APG demonstration. The results of data collection efforts at the Remington Woods, CT site are given in Section 7.6. A limited amount of data was also collected at the Dalecarlia Woods, Spring Valley, DC site and the results are given in Section 7.7. The results of these demonstrations supported the conclusions ultimately drawn after the APG demonstration.

Revision of the sensor technology was indicated for the MP system to collect sufficient data over an anomaly. A modified version of the EMI sensor was designed and built, replacing the single, vertical axis receiver loop of the original coil with a tri-axial receiver cube. These receiver cubes are identical in design to those used in the CRREL MPV2 system (ESTCP MR-201005). The new sensor elements were designed to have the same form factor as the originals, aiding in system fabrication. The analyses which led to this design selection are discussed in Section 7.8.

The TEMTADS Hand-Held Sensor was designed to package the TEMTADS transient EMI sensor technology into a more compact, hand-held configuration for use in

extremely limiting terrain and for integration with unique positioning technologies such as the SAINT INS demonstrated under ESTCP project MR-200810. The Hand-Held sensor is currently configured to operate in a cued mode, where the target location is already known. A series of approximately 40 monostatic measurements are made over each target using a template for precise, relative geo-location. The TEMTADS Hand-Held sensor is shown in Figure 2-5.

Figure 2-5 – The NRL TEMTADS Hand-Held Sensor

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The original TEMTADS 5x5 array was designed to combine the data advantages of a gridded survey with the coverage efficiencies of a vehicular system. The MP system was designed to offer similar production rates in difficult terrain and treed areas that the TEMTADS 5x5 array cannot access. With the upgraded EMI sensors which incorporate the tri-axial receiver cubes, similar performance can be achieved with similar classification-grade data quality.

The MP array is 80 cm x 80 cm, square and mounted on a man-portable cart. Terrain where the vegetation or topography interferes with passage of a cart of that size will not be amenable to the use of the system. For increasingly-difficult survey conditions, the HH system allows for data set to be built up one monostatic element at a time for flexible data collection geometries. As only monostatic measurements can be made with the HH, significantly more measurements are necessary, reducing the production rate.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for the demonstrations are given as a basis for the evaluation of the performance and costs of the demonstrated technologies. Since these are classification technologies, the performance objectives focus on the second step of the UXO remediation problem; that of target classification as UXO, clutter, etc. We assume

that the anomalies from all targets of interest have been detected and have been included on the target list.

These performance objectives apply to the APG demonstrations of each system. For the Remington Woods and Spring Valley demonstrations, the MP system was invited to participate in ongoing remediation efforts without formal demonstration plans. The performances at each site are discussed in Sections 7.6 and 7.7, respectively.

Table 3-1 – Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Quantitative Performance Objectives			
Correct classification of targets of interest	Number of targets of interest identified	• Prioritized dig list • Scoring report from APG	95% correct identification of all targets of interest
Reduction of False Alarms	Number of false alarms eliminated	• Prioritized dig list • Scoring report from APG	Reduction of false alarms by 50% or more with 95% correct identification of munitions
Cued Production Rate	Number of cued targets investigated per day	Log of field work	Hand-Held: 50/day MP 2x2 Cart: 200/day
Analysis Time	Average time required for inversion and classification	Log of analysis work	15 min per target
Qualitative Performance Objectives			
Ease of Use	System can be used in the field without significant issues	Team feedback	Field team has no significant issues to report
Robustness & Reliability	• Number of operational hours recorded per day • Number of significant technical issues	• Field logs of operational hours per day • Field logs of significant technical issues	• ≥ 6 hrs/day • ≤ 1 significant technical issue per day

3.1 CORRECT CLASSIFICATION OF TARGETS OF INTEREST

This is one of the two primary measures of the classification value of the data collected by these sensor systems. By collecting high-quality, precisely relatively-located data, it should be possible to discriminate munitions from scrap and frag with some efficiency. We expected to properly classify a large percentage of the seeded munitions items.

3.1.1 Metric

At a seeded test site such as the APG Standardized UXO Test Site, the metric for classification efficiency is straightforward. We prepared a ranked dig list from the survey data with a UXO / Clutter decision for each Blind Grid cell and for each location in the Indirect Fire Area that the MP 2x2 Cart investigated. ATC personnel used their automated scoring algorithms to assess our results.

3.1.2 Data Requirements

The identification of most of the items in the test field is known to the test site operators. Our ranked dig lists were the input for this metric and ATC's standard scoring was the output.

3.1.3 Success Criteria

The objective was considered to be met for each demonstration if more than 95% of the seeded munitions items were correctly classified.

3.2 OBJECTIVE: REDUCTION OF FALSE ALARMS

This is the second of the two primary measures of the classification value of the data collected by these technologies. By collecting high-quality, precisely relatively-located data, it should be possible to discriminate munitions from scrap and frag with some efficiency. We expected to properly classify a large percentage of the clutter as such.

3.2.1 Metric

At a seeded test site such as the APG Standardized UXO Test Site, the metric for false alarm elimination is straightforward. We prepared a ranked dig list from the survey data with a UXO / Clutter decision for each Blind Grid cell and for each location in the Indirect Fire Area that the MP system investigated. ATC personnel used their automated scoring algorithms to assess our results.

3.2.2 Data Requirements

The identification of most of the items in the test field is known to the test site operators. Our ranked dig lists were the input for this metric and ATC's standard scoring was the output.

3.2.3 Success Criteria

The objective was considered met if more than 50% of the non-munitions items were labeled as no-dig while retaining 95% of the munitions items on the dig list.

3.3 OBJECTIVE: CUED PRODUCTION RATE

Even if the performance of the technologies on the metrics above was satisfactory, there remain economic metrics to consider. Survey efficiency is the metric that was tracked in these demonstrations.

3.3.1 Metric

For cued data collection, the metric is the number of anomalies investigated per day during each demonstration. Combined with the daily operating cost of the technology, these values give the per-anomaly cost of operating each technology.

3.3.2 Data Requirements

Productivity was determined from a review of the demonstration field logs.

3.3.3 Success Criteria

Given the cued data-collection methodology used for these demonstrations, this objective was considered successfully met if the production rates were at least 50 and 200 anomalies per day for the Hand-Held sensor and the MP system, respectively.

3.4 OBJECTIVE: ANALYSIS TIME

Another component of demonstration costs was the amount of analyst time required for data analysis. We tracked the near-real-time analysis time for these demonstrations.

3.4.1 Metric

The time required for inversion and classification per anomaly was the metric for this objective.

3.4.2 Data Requirements

Analysis time was determined from a review of the data analysis logs.

3.4.3 Success Criteria

Since these were the first formal demonstrations of these technologies, the objective was considered successfully met if the average inversion and classification time was less than 15 minutes per anomaly.

3.5 OBJECTIVE: EASE OF USE

This objective represents an opportunity for all parties involved in the data collection process, especially the data collection team, to provide feedback in areas where the process could be improved.

3.5.1 Data Requirements

Discussions with the entire field team and other observations were used.

3.6 OBJECTIVE: RELIABILITY

This objective captures the readiness of the system for live site demonstrations as an integrated system.

3.6.1 Data Requirements

The number of operational hours per day and the frequency of significant technical issues were collected from the demonstration field logs.

4.0 SITE DESCRIPTION

For each of these projects one demonstration was conducted at the APG Standardized UXO Test Site located at the Aberdeen Proving Ground, MD. The MP system was demonstrated in August, 2010 and the HH sensor was demonstrated in October, 2010. The site description for APG is given in Section 4.1. The MP system participated in a pair of small-scale demonstrations at the Remington Woods site in October, 2008 and August, 2009. The Remington Woods site is discussed in Section 4.2. In May, 2010, the MP system made measurements on 107 anomalies in the Dalecarlia Woods site. A brief discussion of the Spring Valley site is provided in Section 4.3.

4.1 APG Standardized UXO Test Site

4.1.1 Site Selection

APG was initially chosen as the site of the first field demonstration for each technology. The APG site is located close to our base of operations in southern Maryland and therefore minimizes the logistics costs of deployment. Use of this site allows us to receive validation results from near-real-world conditions without incurring the logistics and intrusive investigation expenses that would be required for a demonstration at a live site.

4.1.2 Site History

The Standardized UXO Test Site is adjacent to the Trench Warfare facility at the Aberdeen Proving Ground. The specific area was used for a variety of ordnance tests over the years. Initial magnetometer and EMI surveys conducted by the MTADS team

performed after a "mag and flag" survey of the same area identified over a thousand remaining anomalies. These data were used for a final cleanup of the site prior to the emplacement of the original test items. Prior to the two subsequent reconfiguration events, unexplained anomalies identified by demonstrators using the site were also investigated and removed.

4.1.3 Site Topography and Geology

According to the soils survey conducted for the entire area of APG in 1998, the test site consists primarily of Elkton Series type soil [3]. The Elkton Series consist of very deep, slowly permeable, poorly drained soils. These soils formed in silty aeolin sediments and the underlying loamy alluvial and marine sediments. They are on upland and lowland flats and in depressions of the Mid-Atlantic Coastal Plain. Slopes range from 0 to 2 percent.

Overall, the demonstration site is relatively flat and level. There are some low-lying areas in the northwest portion of the site that tend to have standing water during the wet periods of the year. The current sensor systems are moderately weatherproofed, but we did not operate them through standing water. However, during the most recent reconfiguration, the areas most prone to being underwater were excluded from the survey scenarios. Anomalies that were located underwater or nearby to water at the time of survey were deferred until the end of the survey and were interrogated by carefully, if less efficiently, maneuvering the array into position. A small number of the Calibration Area items remained under a sufficient depth of water to be rendered inaccessible to the HH sensor throughout the demonstration.

4.1.4 Munitions Contamination

The area currently occupied by the UXO Site has seen an extensive history of munitions use. As an example, in 2003 we conducted a magnetometer survey of a previously unremediated area directly adjacent to the site [4]. In a survey area of approximately 1 hectare, we identified 2,479 anomalies, of which 1,921 were amenable to a model fit using our standard analysis. Historical records provided by ATC and previous remediation results indicated that the likely munitions of interest for this site were:

- Grenades, MkI, MkII, and French VB Rifle w/o chute
- Grenades, French VB Rifle w/ chute
- 60mm mortars (including 2" Smoke)
- 3" Stokes (Smoke and HE)
- 105 mm projectiles
- 155 mm projectiles

4.1.5 Site Geodetic Control Information

There are two first-order points on the site for use as GPS base station points. Their reported coordinates are listed in Table 4-1. The horizontal datum for all values is NAD83. The vertical control is referenced to the NAVD88 datum and the Geoid03 geoid. All anomaly list locations for the APG demonstrations were flagged by APG geodetics personnel using their standard techniques.

Table 4-1 – Geodetic Control at the APG Standardized UXO Test Site

ID	Latitude	Longitude	Elevation	Northing	Easting	HAE
477	39º 28' 18.63880" N	76º 07' 47.71815"W	10.669 m	4,369,749.013	402,810.038	-22.545
478	39º 28' 04.24219" N	76º 07' 48.50439"W	11.747 m	4,369,305.416	402,785.686	-21.473

4.1.6 Site Configuration

Figure 4-1 is a map of the Standardized UXO Technology Demonstration Site at APG. The Calibration and Blind Grids are shown along with the various Open Field Areas.

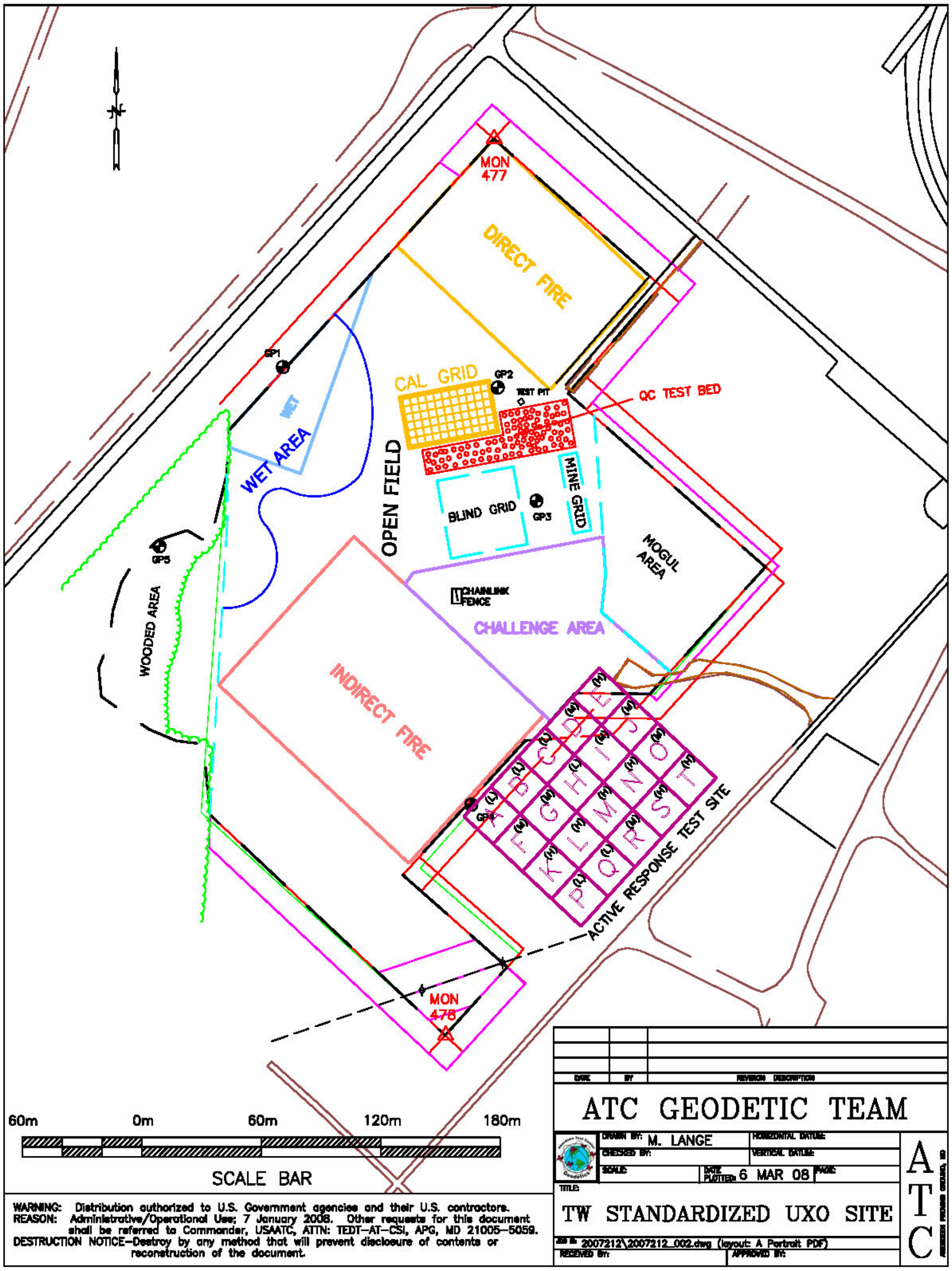


Figure 4-1 – Map of the reconfigured APG Standardized UXO Test Site.

4.2 Remington Woods, CT

4.2.1 Site Selection

The Remington Woods site in Bridgeport, CT is part of the former Remington Arms Lake Success property. SAIC has been supporting the UXO remediation efforts of the current property owners, DuPont Corporation, for a number of years. Advanced data collection and data analysis techniques have been applied to expedite the remediation effort on site with the support of all stakeholders. Based on discussions with the site team, the MP system was invited to conduct side-by-side data collection and analysis efforts with the current process (which will be described in more detail in Section 7.6) where the MP system would collect data over selected flags already placed for remediation by the current process. The data would be analyzed and a dig list prepared. Since these flags were already scheduled for remediation, ground truth was available for determining the system performance.

4.2.2 Site History

The site was used by Remington Arms until 1989 for production, testing, storage, and disposal of small and large caliber ammunition and powders. DuPont Corporation and URS Corporation have been working to clean up the site since 2002.

4.2.3 Site Topography and Geology

The site is mostly covered with tall trees and dense thorny underbrush. The underbrush is cleared from the current work area each year to increase productivity. Many large rock formations are distributed over the site as well. Several structures related to the testing and development of munitions are scattered throughout the site. A 25-acre lake is located at the center of the site.

Figure 4-2 – A view of the Remington Woods site.

4.2.4 Munitions Contamination

Munitions items found at the site tend to be small (37mm - 57mm) and shallow (the depth distribution of excavated “potential UXO” contacts is shown in the plot below)

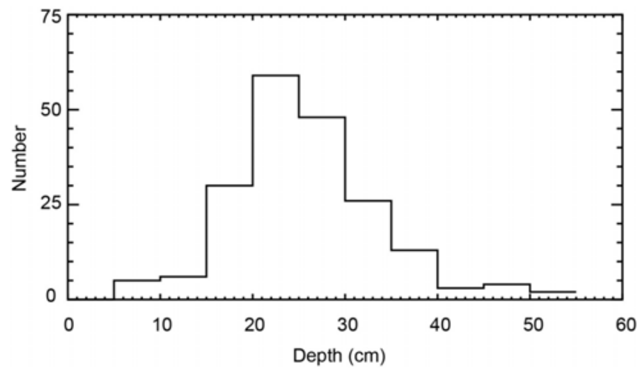


Figure 4-3 – Depth distribution of UXO found at the Remington Woods site.

4.2.5 Site Geodetic Control Information

The site team placed all target flags using their standard techniques. Therefore no information regarding geodetic control was provided to us.

4.2.6 Site Configuration

The 422-acre site is located in Bridgeport and Stratford, CT. A 25-acre lake is located at the center which was not part of these demonstrations. Each year’s efforts are focused on a 40 to 80-acre subarea. A schematic map of the site is shown in Figure 4-4.

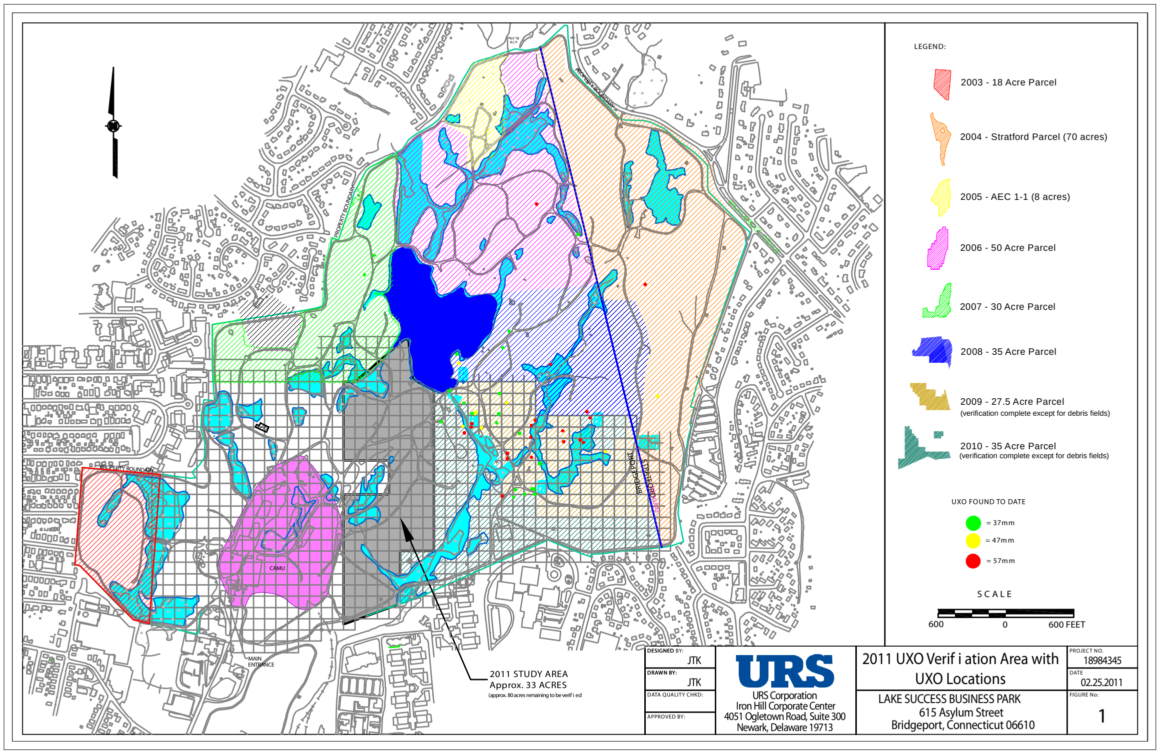


Figure 4-4 – Map of the Remington Woods, CT.

4.3 Dalecarlia Woods, Washington, DC

4.3.1 Site Selection

The U.S. Army Corps of Engineers, Huntsville has an Innovative Technologies Program for investing new UXO technologies for use by the community. Under funding from this program, the Dalecarlia Woods site was selected because of its proximity to NRL, SAIC-ASAD, and the MTADS home facilities. This effort was conducted with cooperation from the USACoE, Baltimore district.

4.3.2 Site History

The Spring Valley Formerly Used Defense Site (FUDS) consists of approximately 661 acres in the northwest section of Washington, DC [5]. During the World War I era, the site was known as the American University Experiment Station (AUES), and was used by the U.S. Government for research and testing of chemical agents, equipment and munitions. Today, the Spring Valley neighborhood encompasses approximately 1,200 private homes, including several embassies and foreign properties, as well as the American University and Wesley Seminary.

In 1993, a contractor digging a utility trench in Spring Valley discovered buried munitions (UXO) [6]. 141 items (43 suspect chemical items) were removed through the resulting emergency response. In February 1993, the USACE began to conduct a

remedial investigation of the site. The investigation by the USACE focused on specific sites that were determined to have the potential for contamination. Following a two-year investigation, the USACE found four munitions and no additional chemical warfare materiel. In 1995, a No Further Action Decision Document covering most of the site was signed, while acknowledging the Army's responsibility for follow-up action if needed.

The USACE, at the encouragement of the regulatory community, returned to the FUDS in 1998 and conducted further investigation on the residence of the Ambassador of South Korea. This investigation yielded several burial pits containing munitions items, many of which were filled with chemical warfare materiel. The USACE expanded the investigation to include every property located in the FUDS boundary. This investigation included the identification and removal of arsenic contaminated soil, a groundwater investigation, and the search for additional munitions, both in burial pits and isolated items on residential properties.

A full history of this work is available at the Spring Valley web site [5].

4.3.3 Site Topography and Geology

The demonstration site is primarily gently rolling hills with some steep banks at the edge of streams. There is moderate tree cover on the site, as seen in Figure 4-5. There is significant ground cover and large, fallen trees throughout the area.

Figure 4-5 – A view of the Dalecarlia Woods area

4.3.4 Munitions Contamination

A more complete discussion of the munitions and munitions-related materials that have been found within the FUDS is available at the official website [5]. This effort was focused on 75mm projectiles, 4-in Stokes Mortars, and Livens Projectors.

4.3.5 Site Geodetic Control Information

The site team placed all target flags using their standard techniques. Therefore no information regarding geodetic control was provided to us.

4.3.6 Site Configuration

The site has been divided into a series of sub-areas (by location) and grids within those areas. Three grids were made available in the Dalecarlia Woods area for the demonstration.

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

Each demonstration was designed to be executed in two stages. The first stage was to characterize the response of the sensor system with respect to the items of interest and to the site-specific geology. Characterization of the sensor response to the items of interest was conducted at our home facility using both test stand and test field measurements prior to deployment. The background response of the demonstration site, as measured by the sensor systems, was characterized throughout data collection. If any items of interest were only available onsite, onsite characterization measurements would be made during the demonstration.

The second stage of each demonstration was a survey of the demonstration site using the specified sensor system. The system (or template) was positioned roughly over the center of each anomaly on the source anomaly list and a data set collected. Each data set was then inverted using the data analysis methodology discussed in Section 6.0, and estimated target parameters determined.

The target list for each demonstration was developed from previously acquired geophysical data analysis. For example, for the MP system demonstration at APG, the same target list that was developed for the TEMTADS 5x5 array demonstration at APG was used to provide the best system-to-system comparison. The data collection process is described in more detail for each of the sensor systems in the following two sections.

5.1.1 TEMTADS Hand-Held Sensor

For the APG demonstration of the HH sensor, the union of the Blind Grid target lists from the previous EM61-HH / SAINT and TEMTADS 5x5 demonstrations were used as the target list. This allowed for a direct, head-to-head comparison of the results with those of the EM61-HH / SAINT configuration and comparisons with the TEMTADS 5x5 array and MP system.

A wooden template was positioned over each target in turn. A series of 40 individual measurements was then made using the template as a precise guide for relative location.

For each measurement, the system activated the transmitter and collected decay data from the Rx coil. The sensor was then moved to each template position in turn, and the next set of data was collected. In addition to the positions on the template, in-air and near-surface background locations were included as shown schematically in Figure 5-1 b). The position numbering on the schematic indicates the recommended order of collection. The complete set of data for each target was then inverted for target characteristics. Complete coverage of the survey areas depended on weather and water levels in sections with poor drainage.

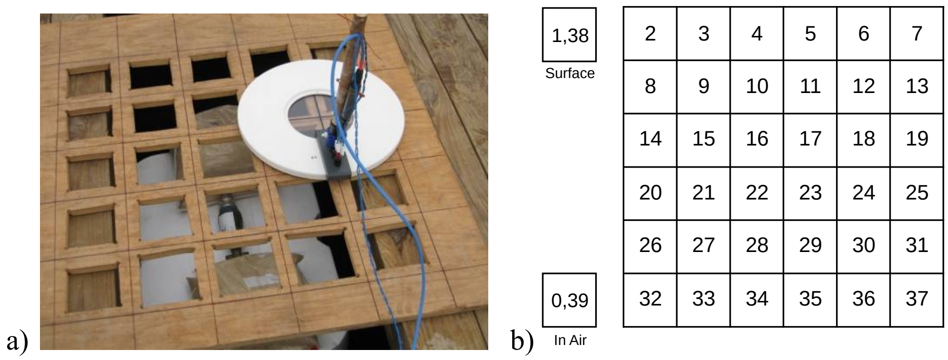


Figure 5-1 – The position template a) over a test article and b) shown schematically.

5.1.2 TEMTADS MP 2x2 Cart

The MP system was positioned roughly centered over each target flag. Once positioned, data were collected while firing each transmitter in sequence. In previous testing [2], we found demonstrable value in collecting a second set of data at a location approximately 20 cm (1/2 a sensor width) off the anomaly center, particularly for deeper targets. This process was continued for these demonstrations. Analyses of the results with and without this second data set were included in our assessment of the performance of the MP system. See Section 7.8 for further details. The anomaly lists for the Blind Grid and the Indirect Fire Areas were the same ones used for the TEMTADS 5x5 array demonstration in June 2008 [7]. A cued data collection was made for each anomaly position. Complete coverage of these areas depended on weather and water level in sections with poor drainage.

5.2 SITE PREPARATION

Basic facilities such as portable toilets and field buildings were provided. Secure storage for the sensor systems was available in the field buildings on site. Site personnel placed plastic pin flags with the flag number clearly marked at each flag position using their standard techniques prior to each demonstration.

5.3 SYSTEMS SPECIFICATION

These demonstrations were conducted using the NRL TEMTADS Hand-Held Sensor and the TEMTADS MP 2x2 Cart.

5.3.1 TEMTADS Array Configuration and Electronics

The standard TEMTADS TEM sensor has dimensions of 40 cm x 40 cm. Sensors are positioned at a ride height of 10 - 20cm above the ground to minimize the effects of ground response while maximizing the depth of targets for which classification grade data can be collected. Each sensor platform is constructed of one or more of these sensors, yielding cross-track and down-track separation of 40 cm for array configurations. The transmitter electronics and the data acquisition computer are mounted in the operator backpack, as shown in Figure 5-2. Custom software written by NRL provides data acquisition functionality. After the sensor/array is positioned roughly centered over the center of the anomaly, the data acquisition cycle is initiated. Each transmitter is fired in a sequence. The received signal is recorded for all Rx channels for each transmit cycle. The transmit pulse waveform duration is 2.7 s (0.9s block time, 9 repeats within a block, 3 blocks stacked, with a 50% duty cycle). While it is possible to record the entire decay transient at 500 MHz, we have found that binning the data into 122 time gates simplifies the analysis and provides additional signal averaging without significant loss of temporal resolution in the transient decays [8]. The data are recorded in a binary format as a single file with four data points (one data point per Tx cycle). The filename corresponds to the anomaly ID from the target list under investigation.

Figure 5-2 – TEMTADS 2x2 Electronics Backpack

5.3.2 Data Acquisition User Interface

The data acquisition computer is mounted on a backpack worn by one of the data acquisition operators. The second operator controls the data collection using a personal data assistant (PDA) which wirelessly (IEEE 802.11b) communicates with the data acquisition computer. The second operator also manages field notes and team

orienteering functions. Data collection with the MP system at the former Camp Beale, CA is shown in Figure 5-3.

Figure 5-3 – TEMTADS MP 2x2 Cart and Data Acquisition Operators

5.3.3 Hand-Held TEMTADS Sensor System

The HH sensor is deployed on a raised template resulting in a sensor-to-ground offset of up to 25 cm. The optimum sensor height is dependent on the background ground response and is determined on a site-by-site basis. The HH sensor is shown in Figure 2-5. At this point in the project, the system operates in a cued mode only. The locations of the anomalies must already be known and flagged for reacquisition. In the future, the system will be equipped with GPS and/or other positioning systems.

5.3.4 TEMTADS MP 2x2 Cart

The MP system is a man-portable system comprised of four of the EMI sensors developed for the NRL TEMTADS 5x5 array arranged in a 2x2 array as shown schematically in Figure 5-4. The MP system, shown in Figure 5-5 at APG, is fabricated from PVC plastic and G-10 fiberglass. The center-to-center distance is 40 cm yielding an 80 cm x 80 cm array. The array is deployed on a set of wheels resulting in a sensor-to-ground offset of approximately 25 cm. At this point in the project, the system operates in a cued mode only. The locations of the anomalies must already be known and flagged for reacquisition. In the future, the system will be equipped with GPS and/or other positioning systems and be able to operate in a detection mode.

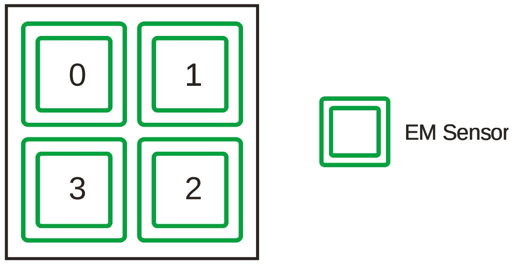


Figure 5-4 – Sketch of the TEMTADS MP 2x2 sensor array showing the position of the four sensors. The standard MR-200601 sensors are shown schematically.

Figure 5-5 – The NRL TEMTADS 2x2 Man-Portable Cart

5.3.5 TEMTADS MP 2x2 Cart w/ Tri-axial Receiver Cubes

The upgraded MP system with the tri-axial receiver cubes is comprised of four individual EMI sensors in the same configuration as the original 2x2 array, as shown schematically in Figure 5-6. The center-to-center distance is 40 cm yielding an 80 cm x 80 cm array.

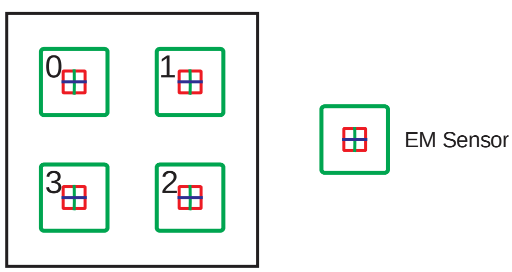


Figure 5-6 – Sketch of the EMI sensor array showing the position of the four sensors. The tri-axial, revised EMI sensors are shown schematically.

5.4 CALIBRATION ACTIVITIES

5.4.1 TEMTADS Sensor Calibration

For the TEMTADS family of sensors, a significant amount of data has been previously collected, both on test stands and under field conditions at our test field [9] and during our recent demonstrations at APG [2,10], SLO [11], Bridgeport, CT [2], and at the former Camp Butner, NC [12]. These data and the corresponding fit parameters provide us with a set of reference parameters including those of clear background (i.e. no anomaly present).

Daily calibration efforts consisted of collecting background (no anomaly) data sets periodically throughout the day and during the APG demonstrations. The background (no anomaly) data sets were collected at known quiet spots to monitor the system noise floor and for background subtraction of signal data.

5.4.2 Background Data

A group of anomaly-free areas throughout each demonstration site were identified in advance from available data, MTADS magnetometer data in the case of APG, for example. For the MP system, the background variation is presented as the mean and standard deviation of the four monostatic measured signals at a decay time of 42 µs (7^{th} time gate). For the APG demonstration, the results for all 86 background measurements taken for the duration of the demonstration (August 30 – September 2, 2010) are shown in Figure 5-7. Julian date codes (day of the year) are used to label the horizontal axis. Table 5-1 provides the intraday variations of the mean and standard deviation quantities of Figure 5-7.

These variations have been correlated in the field with both ambient temperature and the moisture level in the soil surface / vegetation. Background levels tend to be high in the morning, and on a typical field day, the mornings are cool and dew / frost may be present on the ground. As seen in Figure 5-7 on Julian dates 243 and 244 and in Reference 12, as the day progresses the background level tends to decrease, which correlates with increased ambient temperature as well as evaporation of any moisture. It is possible that this effect is caused by changes in the coil impedances associated with changing temperature and / or humidity. However, we cannot rule out soil / vegetation conductivity effects on the background signal. Moisture alone can cause an increased background value, as was seen in Reference 12 on July 17, 2010. During rain events, the background level could double rapidly and would recover on the hour time scale.

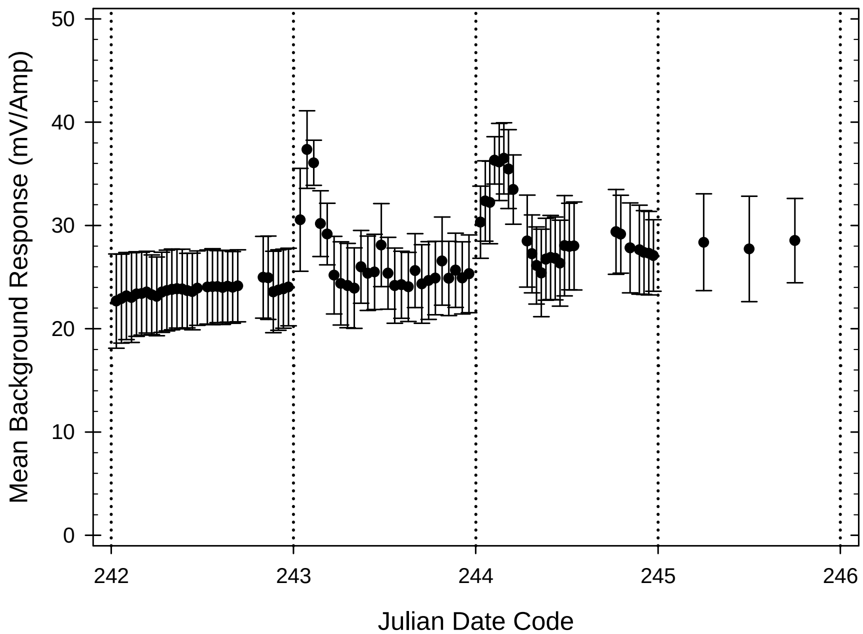


Figure 5-7 – Intra- and inter- daily variations in the response of the MP system to background anomaly-free areas at a time gate of 42 μs through the duration of the demonstration at APG.

Table 5-1 – Summary of the daily variation in the mean and standard deviation of the responses measured by the MP system for the background areas at a time gate of 42 μs at APG.

Date	# of Bkgs.	Mean (mV/Amp)	Std. Dev. (mV/Amp)
8/30/2010	31	23.74	3.84
8/31/2010	26	26.56	3.64
9/1/2010	26	29.49	3.92
9/2/2010	3	28.21	4.62

The background variation analysis results for the Remington Woods, CT (24 measurements) and Dalecarlia Woods, DC (13 measurements) demonstrations are given in Figure 5-8 and Table 5-2 and Figure 5-9 and Table 5-3, respectively. The Remington Woods, CT and Dalecarlia Woods, DC demonstrations covered the periods of August 4 – 6, 2009 and May 21, 2010, respectively.

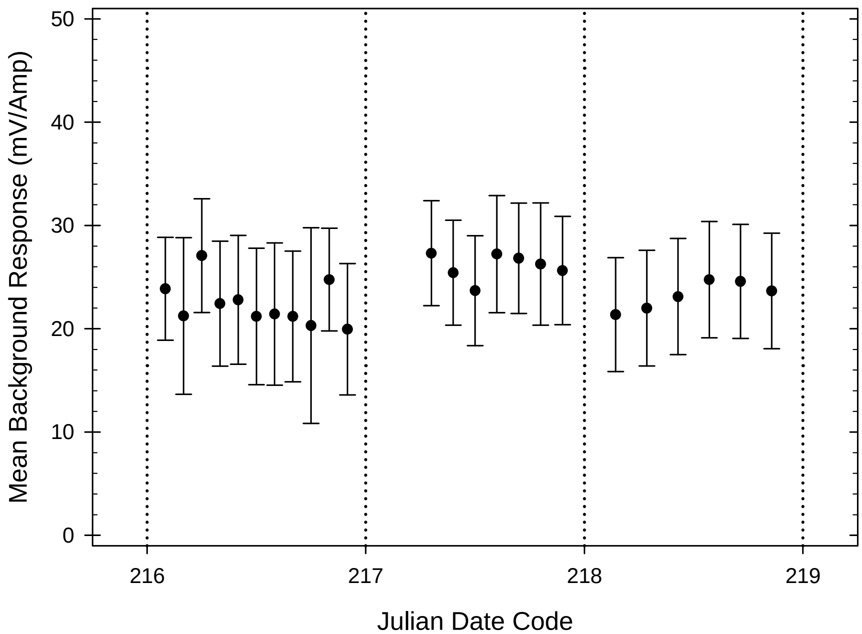


Figure 5-8 – Intra- and inter- daily variations in the response of the TEMTADS MP 2x2 array to background anomaly-free areas at a time gate of 42 μs for the Remington Woods, CT demonstration.

Table 5-2 – Summary of the daily variation in the mean and standard deviation of the responses measured by the TEMTADS MP 2x2 array for the background areas at a time gate of 42 μs at the Remington Woods, CT demonstration site.

Date	**# of Bkgs.**	**Mean (mV/Amp)**	**Std. Dev. (mV/Amp)**
8/4/2009	11	22.39	6.45
8/5/2009	7	26.05	5.38
8/6/2009	6	23.25	5.58

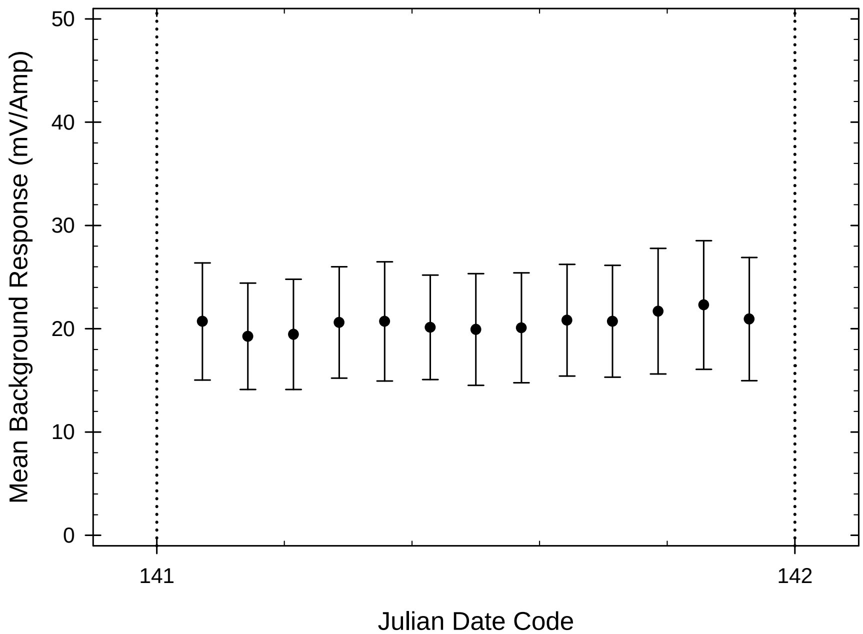


Figure 5-9 – Intra- and inter- daily variations in the response of the TEMTADS MP 2x2 array to background anomaly-free areas at a time gate of 42 μs for the Dalecarlia Woods, DC demonstration.

Table 5-3 – Summary of the daily variation in the mean and standard deviation of the responses measured by the TEMTADS MP 2x2 array for the background areas at a time gate of 42 μs at the Dalecarlia Woods, DC demonstration site.

Date	**# of Bkgs.**	**Mean (mV/Amp)**	**Std. Dev. (mV/Amp)**
5/21/2010	13	20.57	5.55

The electrical behavior of the HH sensor is somewhat modified from that of the standard TEMTADS coil due to the geometry of its construction, as discussed in Section 2.1.2. These differences require that a different decay time, 118 μs, be used for monitoring the background response of the system. A measurement of the in-air and on-ground background is made prior to and after each measurement cycle, as described in Section 5.1.1. All 808 measurement of in-air and on-ground background are shown in Figure 5-10. Table 5-4 provides the intraday variations of the mean and standard deviation quantities of Figure 5-10. As the early-time waveforms of the two sensors differ and different time gates are monitored, the magnitudes of the background responses should not be directly compared. However, the relative trends can be compared.

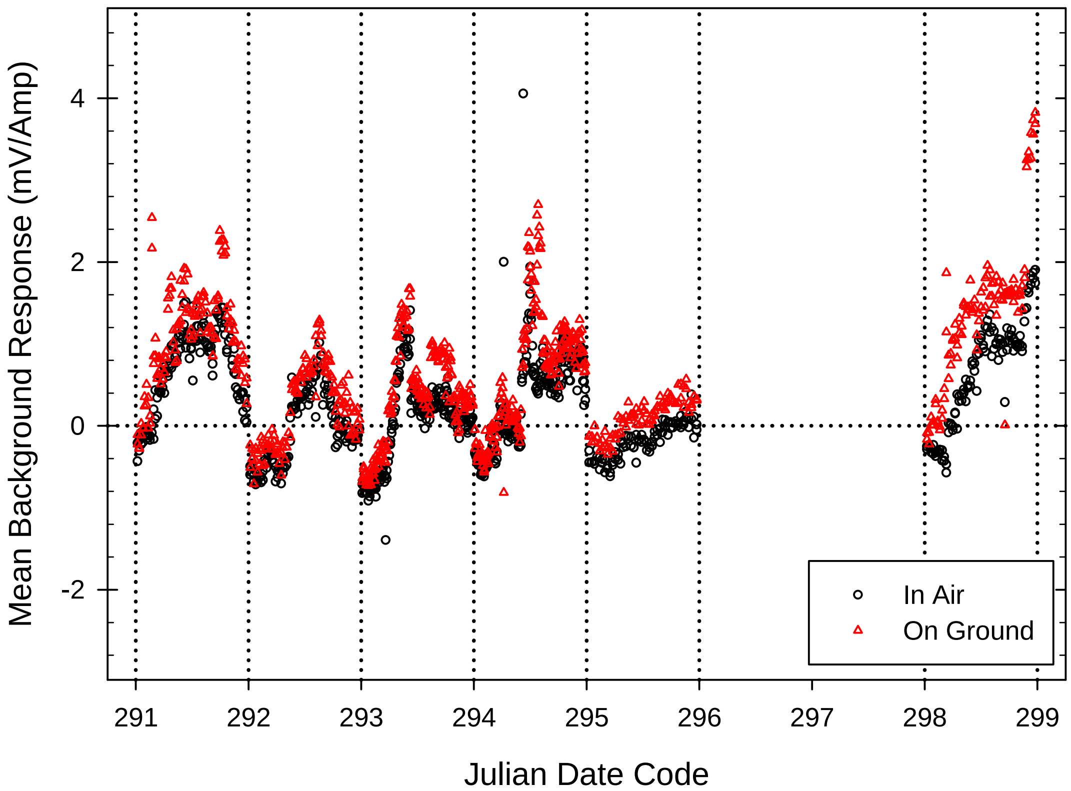


Figure 5-10 – Intra- and inter- daily variations in the response of the TEMTADS Hand-Held Sensor to background anomaly-free areas at a time gate of 118 µs for the APG demonstration.

Table 5-4 – Summary of the daily variation in the mean and standard deviation of the response measured by the TEMTADS Hand-Held Sensor for the background areas at a time gate of 118 µs at APG.

Date	# of Bkgs.	Air Mean (mV/Amp)	Air Std. Dev. (mV/Amp)	Ground Mean (mV/Amp)	Ground Std. Dev. (mV/Amp)
10/18/2010	62	0.71	0.50	0.97	1.61
10/19/2010	61	-0.27	2.58	0.13	1.02
10/20/2010	91	0.07	0.53	0.05	4.27
10/21/2010	97	0.36	0.61	0.64	0.73
10/22/2010	42	-0.42	2.14	0.11	0.22
10/25/2010	51	0.65	0.66	1.40	0.91

5.4.3 Performance at APG – 60mm Mortars

For recent live site demonstrations, the day-to-day performance of a technology is often demonstrated through the use of an Instrument Verification Strip (IVS). The intent of an

IVS is to provide the ability to verify the repeatability of the system response on several examples of items of interest. Each emplaced item in the IVS would be measured twice daily, once before starting the data collection process and a second time before shutting the system down at the end of each day. The APG Standardized UXO Test Site has a previously emplaced, large (66 item) Calibration Area for demonstrators to use and a single, shallow pit for placing other objects. As such, demonstrations at APG measure the Calibration Area items a single time prior to moving on to the Blind Grid and Open Field Areas. Therefore to demonstrate the day-to-day variability of the recovered parameters for each of the sensor technologies, the results for a single munitions type are shown in aggregate for each system. Except for the Calibration Area, the ground truth is held close at ATC and not available to the demonstrators. Items believed to be 60mm mortars are used in the following examples. No IVS-like facilities were available at Remington Woods, CT or Dalecarlia Woods, DC, so no such comparisons are shown.

For reference, the performance of the TEMTADS 5x5 array is shown in Figure 5-11. The fit-result principle magnetic polarizabilities are shown in black, red, and green, respectively. The mean and a 2σ envelope for the axial and transverse polarizabilities are shown in magenta and black, respectively.

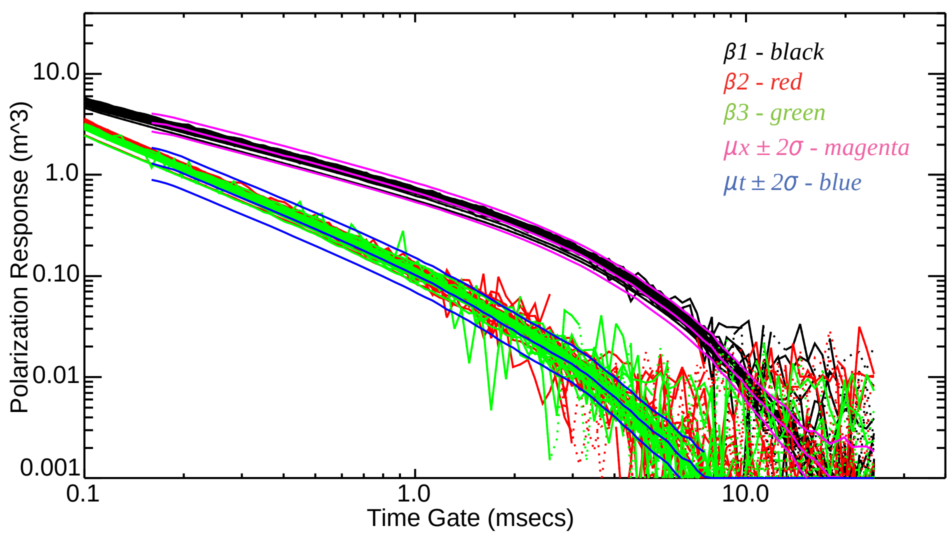


Figure 5-11 – TEMTADS 5x5 array derived response coefficients for all items at APG classified as 60mm mortars.

The analysis results for the same items with the MP system and HH sensor are shown in Figure 5-12 and Figure 5-13, respectively. The HH system's performance was quantitatively similar to that of the full TEMTADS 5x5 array. The performance of the MP system was significantly degraded. See Section 7.8 for further discussion of the MP system performance.

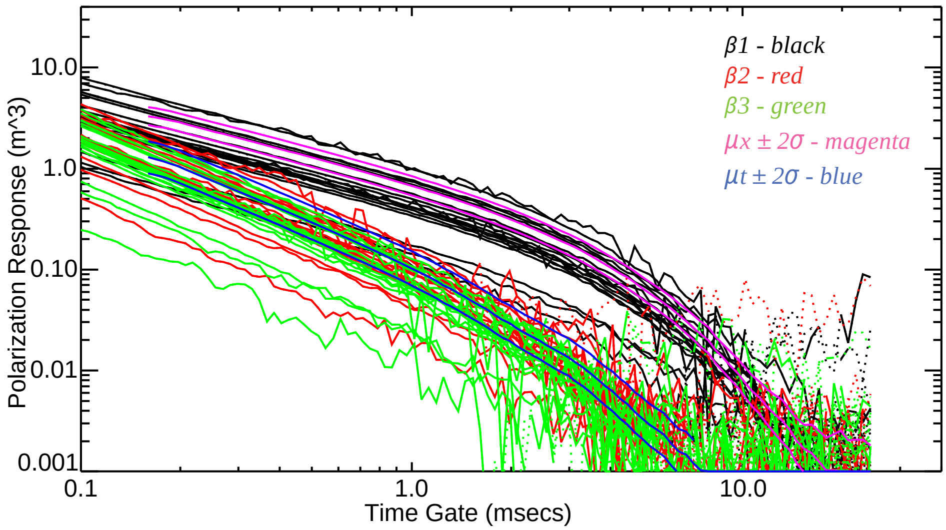


Figure 5-12 – TEMTADS MP 2x2 Cart array derived response coefficients for all items at APG classified as 60mm mortars.

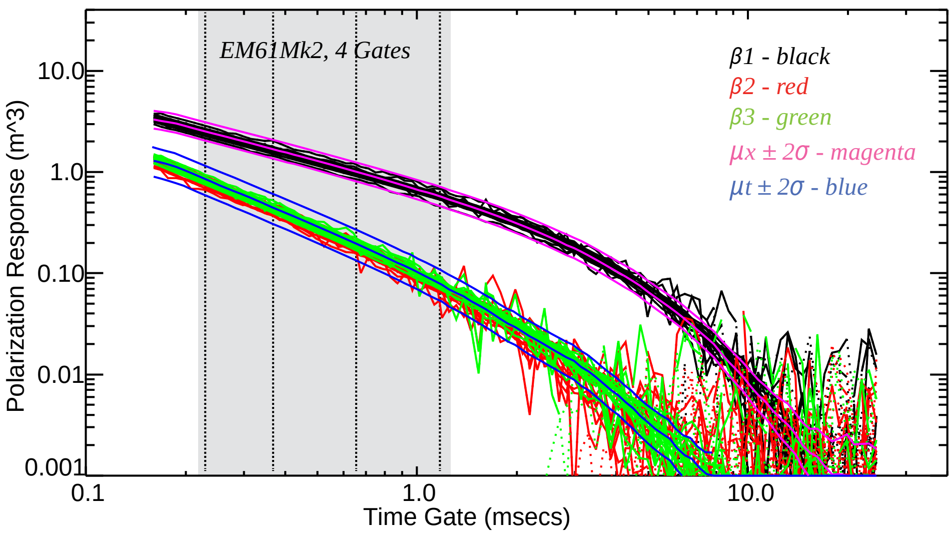


Figure 5-13 – TEMTADS Hand-Held Sensor derived response coefficients for all items at APG classified as 60mm mortars.

5.5 DATA COLLECTION PROCEDURES

5.5.1 Scale of the Demonstrations

The HH sensor demonstration was conducted at the APG Standardized UXO Test Site. The Calibration Area and the Blind Grid Areas were surveyed. Only those cells in the Blind Grid Area that were on the union of the TEMTADS (MR-200601) and SAINT (MR-200810) target lists were surveyed with the HH sensor. The MP system demonstration at the same site covered the Calibration Area, and the Blind Grid and

Indirect Fire Areas, using the original TEMTADS target list. The Remington Woods and Dalecarlia Woods demonstration were conducted on the respective sites using provided target lists from the ongoing remediation efforts. For all sites, the locations on the target lists were previously reacquired and flagged.

5.5.2 Sample Density

The EMI data spacing for the MP system is fixed at 40 cm in both directions by the array design. Two set of data were collected for each flag position as described in Section 5.1.2. The HH sensor data are collected on a 6x6 grid template with 15-cm grid spacing. In-air and ground background measurements are taken on a known quiet spot within a few steps of the flag location.

5.5.3 Quality Checks

Preventative maintenance inspections were conducted at least once a day by all team members, focusing particularly on the sensors and cabling. Any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios were available in the system spares inventory which was on site.

Two data quality checks were performed on the EMI data. After background subtraction, the data are plotted as a function of time for each transmitter/receiver pair. An example plot is shown in Figure 5-14 for the MP system and APG Calibration Area item G02, a 37mm projectile buried at a depth of 24 cm below the surface. The plots were visually inspected to verify that there was a well-defined anomaly without extraneous signals or dropouts. Further QC evaluation on the transmit/receive cross terms was based on the dipole inversion results. An example of the inversion results (principle polarizability decays) is shown in Figure 5-15 for the data shown in Figure 5-14. Our experience has been that data glitches show up as a degraded match of the extracted response coefficients to the reference values, when appropriate. This is quantitatively seen as a reduced fit coherence. The fit coherence is a value (0 – 1) reflecting how well the fit result response coefficients reproduce the collected data. Qualitative evaluation is also conducted by visual inspection of several QC plots by the data analyst.

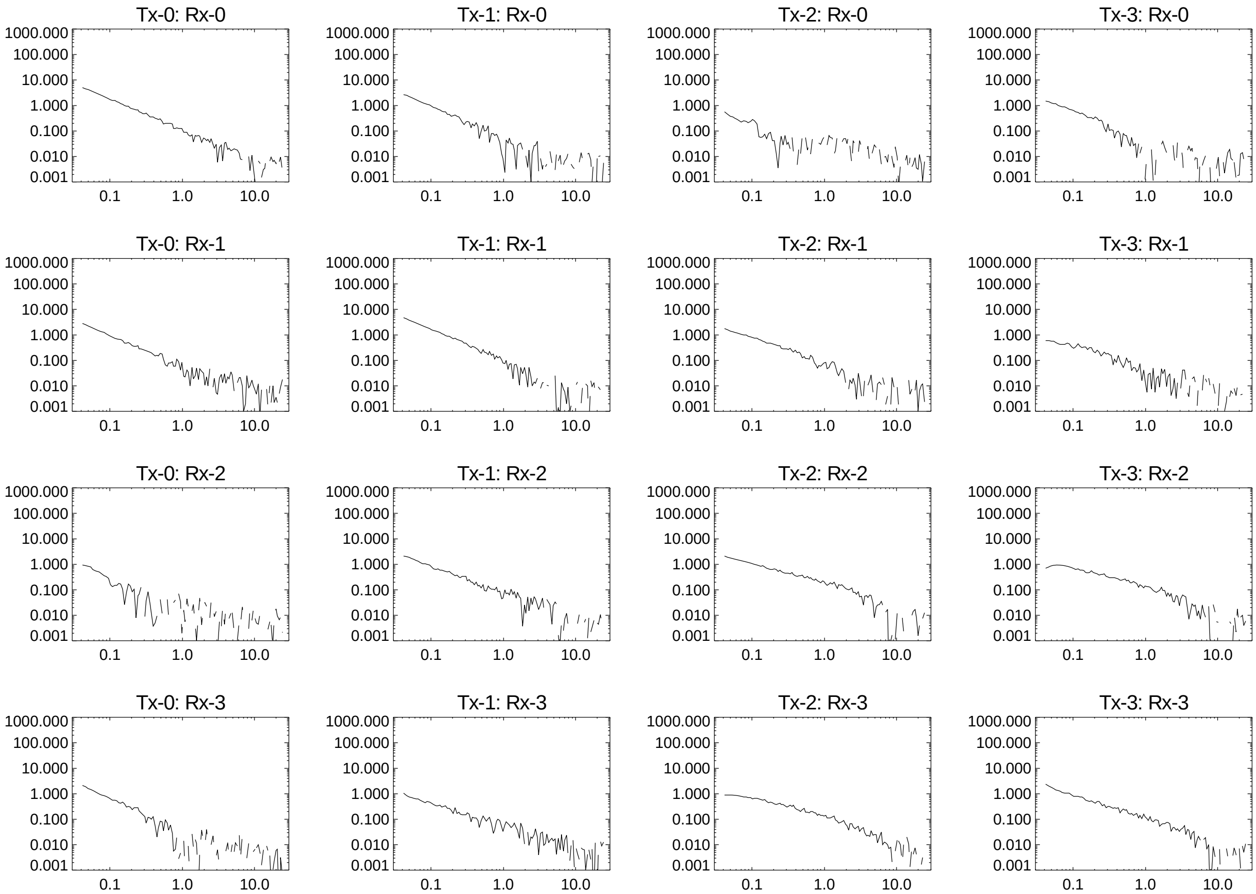


Figure 5-14 – TEMTADS MP 2x2 Cart QC plot for APG Calibration Area item G002, a 37mm projectile at a depth of 24 cm below the surface.

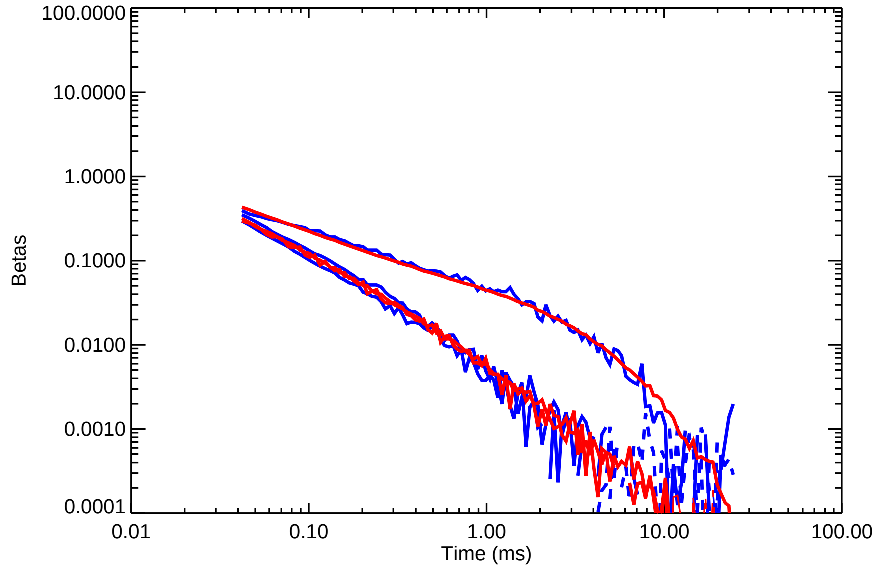


Figure 5-15 – TEMTADS MP 2x2 Cart derived response coefficients for APG Calibration Area item G002, a 37mm projectile at a depth of 24 cm below the surface. The blue lines are the fit results for the collected data and the red lines indicate a library entry for a 37mm projectile.

Any data set deemed unsatisfactory by the data analyst was flagged and not processed further. The anomaly corresponding to the flagged data was logged for re-acquisition by the field team.

5.5.4 Data Handling

Data were stored electronically on the backpack data acquisition computer hard drive. Approximately every two hours, the field data were copied onto removable media and transferred to the onsite data analyst for QC/analysis. The data were moved onto the data analyst's computer and the media was recycled. Raw data and analysis results were backed up from the data analyst's computer to external hard disks daily. These results are archived on an internal file server at SAIC at the end of the survey. All field notes / activity logs were written in ink and stored in archival laboratory notebooks. These notebooks are archived at NRL and SAIC. Dr. Tom Bell is the POC for obtaining data and other information. His contact information is provided in Appendix A of this report.

5.6 VALIDATION

Validation of the performance of these technologies comes primarily from comparison of the classification results of the data analysis to the ground truth. In the case of the APG Standardized UXO Test Site, the ground truth is known to the site managers and no intrusive investigation is required. For the Remington Woods and Dalecarlia Woods sites, the targets selected for investigation were already scheduled for intrusive

investigation as part of the ongoing cleanup efforts at each site. Ground truth results were provided after the intrusive investigations were complete.

5.6.1 Aberdeen Proving Ground, MD

With the exception of the Calibration Areas, the ground truth for the Standardized sites is held back from individual technology demonstrators to preserve the utility of the Blind Grid and the Open Field Areas. Results from the Blind Grid and the Indirect Fire Area (for the MP system) were submitted to ATC for performance evaluation. Scoring results have been received and are available [13,14]. A summary of the results are given in Section 7.0.

5.6.2 Remington Woods, CT

The two demonstrations at the Remington Woods, CT conducted for a side-by-side comparison with the current state-of-the-art UXO classification techniques being used on site. Ongoing UXO remediation is based on the results of an EM61-HH cued-template survey following an EM61-Mk2 detection survey. The list of targets investigated with the MP system was a subset of the list prioritized for intrusive investigation based on the EM61 surveys. Each Fall, the items indicated for investigation on the prioritized EM61-based dig list are excavated. Ground truth and photography are then available for the targets investigated by the MP system. A summary of the results is given in Section 7.0.

5.6.3 Spring Valley, Washington, DC

The demonstration at the Dalecarlia Woods, DC was conducted as a side-by-side comparison with the target prioritization techniques being used on site. Ongoing UXO remediation is based on the results of EM61-Mk2 and magnetometer surveys. The list of targets investigated with the MP system was a subset of the list prioritized for intrusive investigation. The items indicated for intrusive investigation on the prioritized dig list were excavated. Ground truth was provided for the targets investigated by the MP system. A summary of the results is given in Section 7.0.

6.0 DATA ANALYSIS PLAN

6.1 PREPROCESSING

6.1.1 TEMTADS Hand-Held Sensor

The HH sensor has one EMI sensor with concentric transmitter and receiver coils. For each transmit pulse, we record the transient decay response at the receiver (12,500 points). The recorded data are then binned into a series of time gates for improved manageability and increased signal-to-noise. Normally we use 122 logarithmically spaced time gates. In preprocessing, the recorded signals are normalized by the transmitter currents to account for any transmitter variations. On average the peak transmitter current is approximately 7.5 Amps. Due to a mis-calibration in the data

acquisition software, the reported currents were half the actual, approximately 3.75 A. This issue has since been resolved. Decay time is measured from the time that transmitter turn-off is initiated. We subtract 0.028 ms from the nominal gate times to account for time delay due to effects of the receive coil, electronics, and the Tx turn-off delay [15]. The correction was determined empirically by comparing measured responses for test spheres with theory. Measured responses include interfering signals due to transmitter ringing and related artifacts out to about 0.160 msec. Consequently we only include response beyond 118 μs in our analysis as the background is too large and varying to be reliably subtracted at earlier times. This leaves 99 gates spaced logarithmically between 0.118 ms and 25.35 ms.

The background response is subtracted from each target measurement using data collected in a nearby target-free region measured at the same height as the template. All background measurements were inter-compared to evaluate background variability and identify outliers which may correspond to measurements over non-ferrous targets. In previous testing at our Blossom Point test field and during other demonstrations, significant background variation was not observed. It has been possible to use blank ground measurements from 100 meters away for background subtraction. Changes in moisture content and outside temperature have been shown to cause variation in the backgrounds, necessitating care when collecting data after weather events such as rain.

6.1.2 TEMTADS MP 2x2 Cart

The MP system has four sensor elements, each comprised of a transmitter coil and a vertically-oriented receiver coil. For each transmit pulse, the responses at all of the receivers are recorded. This results in 16 possible transmitter / receiver combinations in the data set (4 transmitters x 4 receiver cubes). In preprocessing, the recorded signals are normalized by the peak transmitter current to account for any variation in the transmitter output. On average, the peak transmitter current is approximately 7.5 Amps. Due to a mis-calibration in the data acquisition software, the reported currents were half the actual, 3.75 A. This issue has since been resolved. Although the data acquisition system records the signal over 122 logarithmically-spaced time gates, the measured responses over the first 7 gates include interfering signals due to transmitter ringing and related artifacts and are discarded. We subtract 0.028 ms from the nominal gate times to account for time delay due to effects of the receive coil, electronics, and the Tx turn-off delay [15]. The delay was determined empirically by comparing measured responses for test spheres with theory. This leaves 115 gates spaced logarithmically between 0.042 ms and 25.35 ms.

The background response is subtracted from each target measurement using data collected at a nearby target-free background location. As few measurement cycles are required for the MP system (8 vs. 40); the MP system can collect data over more targets/hour than the HH sensor for a given set of data acquisition parameters. Based on previous experience with the MP system and the TEMTADS 5x5 array, a background measurement for the MP system was made approximately every 30 minutes. The same caveats mentioned in the previous Section apply.

6.2 TARGET SELECTION FOR DETECTION

6.2.1 Aberdeen Proving Ground, MD

The anomaly list for the Blind Grid and the Indirect Fire Areas were the same ones as used for the TEMTADS 5x5 array demonstration in June 2008 [7].

6.2.2 Remington Woods, CT

DuPont Corp. and URS Corp. are currently involved in an ongoing UXO remediation effort at this site. The initial target detection is based on the results of an EM61-Mk2 survey. After analysis and prioritization, a cued-template EM61-HH survey is conducted to further refine the diglist prioritization. A prioritized diglist is then generated with three classes of targets. Likely Munitions (Class 1), Possible Munitions (Class 2), and Likely Clutter (Class 3). All Class 1 targets are excavated using robotically-controlled excavators and blast shield. All Class 2 targets are investigated by UXO technicians manually. A statistical sampling (~10%) of the Class 3 targets are investigated for quality control purposes. The list of targets investigated with the MP system was a subset of the original prioritized dig list including the Class 1, Class 2, and the sampled Class 3 targets.

6.2.3 Spring Valley, Washington, DC

The USACE, Baltimore District has an established, ongoing remediation project at the Spring Valley FUDS. Based on extensive geophysical data and review by the Anomaly Review Board, dig lists are prepared for intrusive investigation. A small segment of the dig list for 2010 was selected for investigation based on schedule. All items on the segment of the dig list were investigated and ground truth was provided.

6.3 PARAMETER ESTIMATION

The raw signature data from TEMTADS sensors reflect details of the sensor/target geometry as well as inherent EMI response characteristics of the targets themselves. In order to separate out the intrinsic target response properties from sensor/target geometry effects, we invert the signature data to estimate principal axis magnetic polarizabilities for the targets. The TEMTADS data are inverted using the standard induced dipole response model wherein the effect of eddy currents set up in the target by the primary field is represented by a set of three orthogonal magnetic dipoles at the target location [16]. The measured signal is a linear function of the induced dipole moment $\mathbf{m}$, which can be expressed in terms of a time dependent polarizability tensor $\mathbf{B}$ as

$$\mathbf{m} = \mathbf{U}\mathbf{B}\mathbf{U}^{T} \cdot \mathbf{H}_0$$

where $\mathbf{U}$ is the transformation matrix between the physical coordinate directions and the principal axes of the target and $\mathbf{H}_0$ is the primary field strength at the target. The eigenvalues $\beta_i(t)$ of the polarizability tensor are the principal axis polarizabilities.

Given a set of measurements of the target response with varying geometries or "look angles" at the target, the data can be inverted to determine the local (X,Y,Z) location of the target, the orientation of its principal axes (ϕ,θ,ψ), and the principal axis polarizabilities (β_1,β_2,β_3). The basic idea is to search out the set of nine parameters ($X,Y,Z,\phi,\theta,\psi,\beta_1,\beta_2,\beta_3$) that minimizes the difference between the measured responses and those calculated using the dipole response model. Since the system currently does not know or record the location or orientation of the cart, target location and orientation are known well locally but not well geo-referenced.

For TEMTADS data, inversion is accomplished by a two-stage method. In the first stage, the target's (X,Y,Z) dipole location is solved for non-linearly. At each iteration within this inversion, the nine element polarizability tensor (**B**) is solved linearly. We require that this tensor be symmetric; therefore, only six elements are unique. Initial guesses for X and Y are determined by a signal-weighted mean. The routine normally loops over a number of initial guesses in Z, keeping the result giving the best fit as measured by the chi-squared value. The non-linear inversion is done simultaneously over all time gates, such that the dipole (X,Y,Z) location applies to all decay times. At each time gate, the eigenvalues and angles are extracted from the polarizability tensor.

In the second stage, six parameters are used: the three spatial parameters (X,Y,Z) and three angles representing the yaw, pitch, and roll of the target (Euler angles ϕ,θ,ψ). Here the eigenvalues of the polarizability tensor are solved for linearly within the 6-parameter non-linear inversion. In this second stage both the target location and its orientation are required to remain constant over all time gates. The value of the best fit X,Y,Z from the first stage, and the median value of the first-stage angles are used as an initial guess for this stage. Additional loops over depth and angles are included to better ensure finding the global minimum.

Figure 6-1 shows an example of the principal axis polarizabilities determined from TEMTADS array data. The target, a mortar fragment, is a slightly bent plate about 0.5 cm thick, 25 cm long, and 15 cm wide. The red curve is the polarizability when the primary field is normal to the surface of the plate, while the green and blue curves correspond to cases where the primary field is aligned along each of the edges.

Not every target on the target list exhibited a strong enough TEM response to support extraction of target polarizabilities. All of the data were run through the inversion routines, and the results manually screened to identify those targets that could not be reliably parameterized. Several criteria were used: signal strength relative to background, dipole fit error (difference between data and model fit to data), and the visual appearance of the polarizability curves.

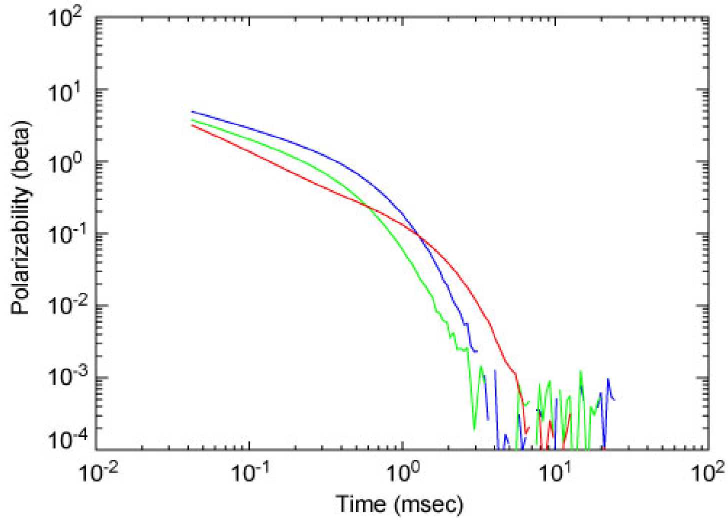


Figure 6-1 – Principal axis polarizabilities for a 0.5 cm thick by 25 cm long by 15 cm wide mortar fragment.

6.4 CLASSIFICATION

Target classification is based on a library matching procedure wherein we compare the quality of both an unconstrained dipole inversion of the TEM array data and the ratio, ρ. ρ is defined as the ratio of the quality of an unconstrained dipole fit of the TEM data to the quality of a dipole fit constrained by principal axis polarizabilities drawn from the signature library. Fit quality is the squared correlation coefficient between the model fit and the data. If ρ is equal to one, then the library item is as good a match to the data as possible. If the value of ρ is small, then the library item is a poor match. For the unconstrained inversion, we utilize an algorithm which compares our derived polarizabilities with a library of known target signatures. The match is based on three criteria: the amplitude of the primary polarizability, and the ratio of the second and third polarizabilities to the first. We have computed match metrics, each of which runs from 0 (terrible match) to 1 (perfect match).

6.5 TRAINING

Our experience with these sensors has been that principle polarizabilities determined from in-air measurements are indistinguishable from those determined from measurements taken over buried targets. We have an extensive collection of inert military munitions collected from many sources which were measured at our home facility using the TEMTADS family of sensors mounted on a test stand. We have also assembled a fairly extensive polarizability database for clutter items recovered from several different sites. This was used as training data for establishing UXO/clutter discrimination boundaries on the coherence ratio ρ and on the direct comparison metric.

6.5.1 Aberdeen Proving Ground

We collected training data in air for all of the 14 standard APG ordnance targets with these EMI sensors. These data were used for the fit library entries. Many of the targets are composites of two or more distinct parts, like a steel body combined with an aluminum tail assembly. Depending on the distance between the sensors and the target, such items can exhibit a range of slightly different EMI signatures corresponding to excitation from different directions. We include measurements with the target oriented nose up, towards the sensor array, nose down, away from the array, flat and obliquely.

6.5.2 Remington Woods, CT

Several recovered munitions were available on site for measurement after being certified as inert. These items along with a set of munitions surrogates developed by DuPont and URS were measured in-air on site during the demonstrations.

6.5.3 Dalecarlia Woods, DC

Training items unique to this site were not readily available and our existing inventory of library signatures was used for this demonstration.

6.6 DATA PRODUCT SPECIFICATIONS

6.6.1 Aberdeen Proving Ground

For the demonstrations conducted at the APG Standardized UXO Test Site, we used the standard reporting templates for the Blind Grid and the Open Field shown below in Figure 6-2 and Figure 6-3. The metrics in Section 3.0 were calculated directly from the Scoring Report provided by the Standardized Test Site administrators. The Discrimination Stage value was the highest coherence ratio for a UXO library entry (using only 60mm and 81mm mortars and the 105mm projectile for the Indirect Fire Area). Classification and Type were determined from the library matching procedure. Depth and Dip values come from the dipole inversion results, the other location and orientation values are not well georeferenced for these systems.

BLIND TEST GRID									
	Letter	Number	Response Stage	Discrimination Stage/Ranking	Classification (Use B for Blank)	TYPE	Depth (M)	Azimuth (Degrees)	Dip (Degrees)
1	A	1							
2	A	2							
3	A	3							
4	A	4							
5	A	5							
6	A	6							
7	A	7							
8	A	8							
...	...	...							

Figure 6-2 – Reporting Template for APG Blind Grid.

INDIRECT FIRE									
	Northing	Easting	Response Stage	Discrimination Stage/Ranking	Classification	TYPE	Depth (M)	Azimuth (Degrees)	Dip (Degrees)
1									
2									
3									
4									
5									
6									
7									
8									
...									

Figure 6-3 – Reporting Template for APG Indirect Fire Area.

6.6.2 Remington Woods, CT

The ongoing efforts at the Remington Woods site provide a starting point for the MP system dig list. The format of the ranked dig list is given in Figure 6-4. The first several columns provide the Target ID # and the ranking from the EM61-MK2 and EM-61 HH surveys for each target to be investigated. The “Field Comments” column is provided to

capture any notes from the field team, *e.g.* "surface item present." The ranking based on the MP system results are given next in the "TEM Category" column, using the same ranking system as was used for the EM61 surveys. As part of the ongoing efforts onsite, a series of munitions simulants were machined for calibration purposes. Our results have shown that the simulants have their own unique decay signatures as compared to the munitions they were designed to simulate. If the fit results for a target were a good match to a simulant signature, it was noted in the "Simulant Match" column. The remaining two ground-truth columns were populated after dig list submission and intrusive investigation were complete.

Target ID#	EM61-MK2 Rank	EM-61 HH Rank	Field Comments	TEM Category	Simulant Match (Yes / No)	Depth (m) Ground Truth	Identification Ground Truth
1							
2							
3							
4							
5							
6							
7							
8							
...							

Figure 6-4 – Reporting Template for Remington Woods, CT.

6.6.3 Dalecarlia Woods, DC

The prioritized diglist for the Dalecarlia Woods demonstration delineated the targets into four categories, 1--Likely Clutter, 2--Cannot Decide, 3--Likely UXO, 4-Cannot Analyze. Overall ranking for target signatures that could be analyzed started with the most likely to be clutter (category #1) and increased through categories 2 & 3. Those signatures that were categorized as "Cannot Analyze" were appended to the end of the diglist. The format of the ranked dig list is given in Figure 6-5.

Target ID #	Rank	Category	Type	Depth (m)
	1			
	2			
	3			
	4			
	5			
	6			
	7			
	…			

Figure 6-5 – Reporting Template for the Dalecarlia Woods, DC demonstration.

7.0 PERFORMANCE ASSESSMENT

The performance objectives for the APG demonstrations are summarized in Table 3-1 and are repeated here as Table 7-1. The results for each criterion are subsequently discussed in the following sections. For the Remington Woods and Spring Valley demonstrations, the MP system was invited to participate in ongoing remediation efforts without formal demonstration plans. The performance at each site is discussed in Sections 7.6 and 7.7, respectively.

Performance objectives for the demonstrations are given as a basis for the evaluation of the performance and costs of the demonstrated technologies. Since these are classification technologies, the performance objectives focus on the second step of the UXO remediation problem; that of target classification as UXO, clutter, etc. We assume that the anomalies from all targets of interest have been detected and have been included on the target list.

Table 7-1 – Performance Results for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria	Success? (Yes/No)
Quantitative Performance Objectives				
Correct classification of targets of interest	Number of targets of interest identified	• Prioritized dig list • Scoring report from APG	95% correct identification of all targets of interest	HH – Yes MP – No
Reduction of False Alarms	Number of false alarms eliminated	• Prioritized dig list • Scoring report from APG	Reduction of false alarms by 50% or more with 95% correct identification of munitions	HH – Yes MP – No
Cued Production Rate	Number of cued targets investigated per day	Log of field work	HH - 50/day MP - 200/day	HH – Yes MP – Yes
Analysis Time	Average time required for inversion and classification	Log of analysis work	15 min/target	HH – Yes MP – Yes
Qualitative Performance Objective				
Ease of Use	System can be used in the field without significant issues	Team feedback	Field team has no significant issues to report	HH – Yes MP – Yes
Reliability and Robustness	• Number of operational hours recorded per day • Number of significant technical issues	• Field logs of operational hours per day • Field logs of significant technical issues	• ≥ 6 hour/day • ≤ 1 significant technical issue per day	HH – Yes MP – Yes

7.1 CORRECT CLASSIFICATION AND REDUCTION OF FALSE ALARMS

7.1.1 Correct Classification of Targets of Interest

This is one of the two primary measures of the classification value of the data collected by these sensor systems. By collecting high-quality, precisely relatively-located data, it should be possible to discriminate munitions from scrap and frag with some efficiency. We expected to properly classify a large percentage of the seeded munitions items.

7.1.1.1. Metric

At a seeded test site such as the APG Standardized UXO Test Site, the metric for classification efficiency is straightforward. We prepared a ranked dig list from the survey data with a UXO / Clutter decision for each Blind Grid cell and for each location in the Indirect Fire Area that the MP system investigated. ATC personnel used their automated scoring algorithms to assess our results.

7.1.1.2. Data Requirements

The identification of most of the items in the test field is known to the test site operators. Our ranked dig lists were the input for this metric and ATC's standard scoring was the output.

7.1.1.3. Success Criteria

The objective was considered to be met for each demonstration if more than 95% of the seeded munitions items were correctly classified.

7.1.2 Objective: Reduction of False Alarms

This is the second of the two primary measures of the classification value of the data collected by these technologies. By collecting high-quality, precisely relatively-located data, it should be possible to discriminate munitions from scrap and frag with some efficiency. We expected to properly classify a large percentage of the clutter as such.

7.1.2.1. Metric

At a seeded test site such as the APG Standardized UXO Test Site, the metric for false alarm elimination is straightforward. We prepared a ranked dig list from the survey data with a UXO / Clutter decision for each Blind Grid cell and for each location in the Indirect Fire Area that the MP system investigated. ATC personnel used their automated scoring algorithms to assess our results.

7.1.2.2. Data Requirements

The identification of most of the items in the test field is known to the test site operators. Our ranked dig lists were the input for this metric and ATC's standard scoring was the output.

7.1.2.3. Success Criteria

The objective was considered met if more than 50% of the non-munitions items were labeled as no-dig while retaining 95% of the munitions items on the dig list.

7.1.3 Results

These Objectives were successfully met for the HH sensor and partially met for the MP system. The HH sensor surveyed anomalies from the union of the TEMTADS and the SAINT target lists for the Blind Grid Area. The MP system surveyed the same anomalies in the Blind Grid and Indirect Fire Areas surveyed during the TEMTADS 5x5 array demonstration. For the HH sensor, the Blind Grid Area discrimination stage results are summarized in Table 7-2 and Table 7-3 (subsets of Table 6a of Reference 13), broken out by munitions type and emplacement depth. For the MP system, the Blind Grid Area discrimination stage results are summarized in Table 7-4 and Table 7-5 (subsets of Table 6a of Reference 14), broken out by munitions type and emplacement depth. For the MP system, the Indirect Fire Test Area discrimination stage results are summarized in Table 7-8 and Table 7-9 (subsets of Table 6c of Reference 14), broken out by munitions type and emplacement depth. The Discrimination Stage Probability of Detection P_d^{disc} is defined as the number of correctly identified munitions divided by the number of emplaced munitions, and the corresponding Probability of False Positive P_{fp}^{disc} is the number of clutter items incorrectly identified as munitions divided by the number of emplaced clutter items. For reference, the corresponding TEMTADS 5x5 array results are provided in Table 7-6, Table 7-7, Table 7-10, and Table 7-11.

The HH sensor successfully met this objective with 96% correct identification of all targets of interest in the Blind Grid Area. The weakest performance was in the 8-12D depth category. The MP system came very close to, but did not successfully meet these criteria in either survey area. The MP system performance was 94% for the Blind Grid and 86% for the Indirect Fire Area. In the both areas, the weakest performance was for the 105mm projectiles. By comparison, the TEMTADS 5x5 array performance statistics were 97% and 92% for the Blind Grid and the Indirect Fire Areas, respectively.

Table 7-2 – TEMTADS Hand-Held Sensor Blind Grid Test Area P_d^{disc} Results

P_d^{disc}	All Types	105-mm	81/60mm	37/25-mm
Munitions Scores	0.96	0.90	0.97	1.00
0 to 4D	1.00	1.00	1.00	1.00
4D to 8D	1.00	1.00	1.00	1.00
8D to 12D	0.56	0.50	0.00	1.00

Table 7-3 – TEMTADS Hand-Held Sensor Blind Grid Test Area P_{fp}^{disc} Results

P_{fp}^{disc}	All Masses	0 to 0.25 kg	>0.25 to 1 kg	>1 to 10 kg
All Depths	0.07	0.03	0.02	0.50
0 to 0.15m	0.06	0.04	0.02	0.50
0.15 to 0.3m	0.13	0.00	0.00	0.50
0.3 to 0.6m	N/A	N/A	N/A	N/A

Table 7-4 – TEMTADS MP 2x2 Cart Blind Grid Test Area P_d^{disc} Results

P_d^{disc}	All Types	105-mm	81/60mm	37/25-mm
Munitions Scores	0.94	0.90	0.97	0.97
0 to 4D	1.00	1.00	1.00	1.00
4D to 8D	0.90	0.50	1.00	0.95
8D to 12D	0.78	0.83	0.00	1.00

Table 7-5 – TEMTADS MP 2x2 Cart Blind Grid Test Area P_{fp}^{disc} Results

P_{fp}^{disc}	All Masses	0 to 0.25 kg	>0.25 to 1 kg	>1 to 10 kg
All Depths	0.40	0.64	0.14	0.40
0 to 0.15m	0.41	0.64	0.11	0.67
0.15 to 0.3m	0.31	0.60	0.29	0.00
0.3 to 0.6m	N/A	N/A	N/A	N/A

Table 7-6 – TEMTADS 5x5 Array Blind Grid Test Area P_d^{disc} Results

P_d^{disc}	All Types	105-mm	81/60mm	37/25-mm
Munitions Scores	0.97	0.93	0.97	1.00
0 to 4D	1.00	1.00	1.00	1.00
4D to 8D	1.00	1.00	1.00	1.00
8D to 12D	0.67	0.67	0.00	1.00

Table 7-7 – TEMTADS 5x5 Array Blind Grid Test Area P_{fp}^{disc} Results

P_{fp}^{disc}	All Masses	0 to 0.25 kg	>0.25 to 1 kg	>1 to 10 kg
All Depths	0.01	0.02	0.00	0.00
0 to 0.15m	0.01	0.02	0.00	0.00
0.15 to 0.3m	0.00	0.00	0.00	0.00
0.3 to 0.6m	N/A	N/A	N/A	N/A

Table 7-8 – TEMTADS MP 2x2 Cart Indirect Fire Test Area P_d^{disc} Results

P_d^{disc}	All Types	105-mm	81/60mm	37/25-mm
Munitions Scores	0.86	0.84	0.88	0.88
By Density				
High	0.81	.085	0.77	0.80
Medium	0.89	0.87	0.89	0.90
Low	0.89	0.81	0.94	0.91
By Depth				
0 to 4D	0.93	0.87	1.00	0.95
4D to 8D	0.79	0.84	0.77	0.71
8D to 12D	0.72	0.50	0.89	0.67

Table 7-9 – TEMTADS MP 2x2 Cart Indirect Fire Test Area P_{fp}^{disc} Results

P_{fp}^{disc}	All Masses	0 to 0.25 kg	>0.25 to 1 kg	>1 to 10 kg
All Depths	0.21	0.26	0.14	0.22
0 to 0.15m	0.21	0.25	0.13	0.33
0.15 to 0.3m	0.20	0.31	0.19	0.12
0.3 to 0.6m	0.17	1.00	0.17	0.00

Table 7-10 – TEMTADS 5x5 Array Indirect Fire Test Area P_d^{disc} Results

P_d^{disc}	All Types	105-mm	81/60mm	37/25-mm
Munitions Scores	0.92	0.93	0.93	0.91
By Density				
High	0.88	0.92	0.91	0.80
Medium	0.94	0.97	0.89	0.97
Low	0.94	0.90	0.97	0.94
By Depth				
0 to 4D	0.96	0.94	0.97	0.97
4D to 8D	0.92	0.94	0.92	0.86
8D to 12D	0.72	0.75	0.78	0.67

Table 7-11 – TEMTADS 5x5 Array Indirect Fire Test Area P_{fp}^{disc} Results

P_{fp}^{disc}	All Masses	0 to 0.25 kg	>0.25 to 1 kg	>1 to 10 kg
All Depths	0.04	0.03	0.02	0.11
0 to 0.15m	0.04	0.04	0.02	0.13
0.15 to 0.3m	0.04	0.00	0.06	0.06
0.3 to 0.6m	0.08	0.00	0.00	0.20

Discrimination Efficiency (E) and False Positive Rejection Rate (R_{fp}) measure the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of munitions detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-munitions items. Efficiency measures the fraction of detected munitions retained after discrimination, while the rejection rate measures the fraction of false alarms rejected. The measures are defined relative to the number of munitions items or the number of clutter items that were actually detected by the sensor.

The HH sensor results for the Blind Grid Area are summarized in Table 7-12, from Table 7a of Reference 13. The MP system results for the Blind Grid and Indirect Fire Test Areas are summarized in Table 7-13 and Table 7-15, from Tables 7a and 7c of Reference 14. Performance levels are shown at two specific operating points on the ROC curve: one at the point where no decrease in P_d is incurred and the other at the operator-selected operating point or threshold. For reference, the results for the TEMTADS 5x5 array demonstration are given in Table 7-14 and Table 7-16.

For the HH sensor, this objective was successfully met, with 99% of emplaced munitions items detected at the operating point with a corresponding false positive rejection rate of 93%. The MP system came very close to meeting this objective. 97% of the emplaced munitions were correctly classified at our selected operating point, with a corresponding false positive rejection rate of 53%. In the Indirect Fire Area, 94% of the emplaced munitions were correctly classified, with a corresponding false positive rejection rate was 54%. For reference, the TEMTADS 5x5 array results for the Blind Grid were 99% of emplaced munitions items were detected at the operating point with a corresponding false positive rejection rate of 99%. For the Indirect Fire Area, the percentages were 98% and 92%, respectively.

Table 7-12 – TEMTADS Hand-Held Sensor Blind Grid Test Area Efficiency and Rejection Rates

	Efficiency (E)	False Positive Rejection Rate
At Operating Point	0.99	0.93
With No Loss of P_d	1.00	0.40

Table 7-13 – TEMTADS MP 2x2 Cart Blind Grid Test Area Efficiency and Rejection Rates

	Efficiency (E)	False Positive Rejection Rate
At Operating Point	0.97	0.53
With No Loss of P_d	1.00	0.15

Table 7-14 – TEMTADS 5x5 Array Blind Grid Test Area Efficiency and Rejection Rates

	Efficiency (E)	False Positive Rejection Rate
At Operating Point	0.99	0.99
With No Loss of P_d	1.00	0.95

Table 7-15 – TEMTADS MP 2x2 Cart Indirect Fire Test Area Efficiency and Rejection Rates

	Efficiency (E)	False Positive Rejection Rate
At Operating Point	0.94	0.54
With No Loss of P_d	1.00	0.01

Table 7-16 – TEMTADS 5x5 Array Indirect Fire Test Area Efficiency and Rejection Rates

	Efficiency (E)	False Positive Rejection Rate
At Operating Point	0.98	0.92
With No Loss of P_d	1.00	0.58

7.2 OBJECTIVE: CUED PRODUCTION RATE

Even if the performance of the technologies on the metrics above was satisfactory, there remain economic metrics to consider. Survey efficiency is the metric that was tracked in these demonstrations.

7.2.1 Metric

For cued data collection, the metric is the number of anomalies investigated per day during each demonstration. Combined with the daily operating cost of the technology, these values give the per-anomaly cost of operating each technology.

7.2.2 Data Requirements

Productivity was determined from a review of the demonstration field logs.

7.2.3 Success Criteria

Given the cued data-collection methodology used for these demonstrations, this objective was considered successfully met if the production rates were at least 50 and 200 anomalies per day for the HH sensor and the MP system, respectively.

7.2.4 Results

This objective was successfully met for both demonstrated systems.

For the HH sensor, 404 target measurements were made over the course of six field days for an average of 67.3 targets/day. These values include any necessary reacquisitions. The lowest daily production rate was 42 targets/day and occurred on the last day of a work week.

For the MP system, 1,073 target measurements were made over the course of four field days for an average of 268.3 targets/day. These values include any necessary reacquisitions. Only 14 targets were measured on the fourth day, with the remainder of the day spent packing equipment and demobilization. The average production rate for the three full days was 353 targets/day.

7.3 OBJECTIVE: ANALYSIS TIME

Another component of demonstration costs was the amount of analyst time required for data analysis. We tracked the near-real-time analysis time for these demonstrations.

7.3.1 Metric

The time required for inversion and classification per anomaly was the metric for this objective

7.3.2 Data Requirements

Analysis time was determined from a review of the data analysis logs.

7.3.3 Success Criteria

Since these were the first formal demonstrations of these technologies, the objective was considered successfully met if the average inversion and classification time was less than 15 min per anomaly.

7.3.4 Results

This Objective was successfully met. For the HH sensor, several minutes were required to invert the data and generate the data quality review and inversion results graphics on our field laptop computer. If any data cleanup / editing was required for a particular data collection, the process would add several minutes of processing time. The average

analysis time amounted to 10 minutes per anomaly. For the MP system, the average inversion time per target was approximately 30 seconds on our field laptop computer. This time includes inverted both data sets individually and then jointly, so that all three sets of results can be evaluated. Including this, the average analysis time amounted to 5 minutes per anomaly. As a result of lessons learned from this undertaking, we expect the average analysis time for future field runs to be less than that obtained here.

7.4 OBJECTIVE: EASE OF USE

This objective represents an opportunity for all parties involved in the data collection process, especially the data collection team, to provide feedback in areas where the process could be improved.

7.4.1 Data Requirements

Discussions with the entire field team and other observations were used.

7.4.2 Results

This Objective was successfully met. Based on operator feedback, there were no significant limitations to the efficient use of either system in the field. Several suggestions were made for additional improvements to the data collection software. They are in the process of being incorporated.

7.5 OBJECTIVE: RELIABILITY

This objective captures the readiness of the system for live site demonstrations as an integrated system.

7.5.1 Data Requirements

The number of operational hours per day and the frequency of significant technical issues were collected from the demonstration field logs.

7.5.2 Results

This objective was successfully met for both systems. No significant downtime was caused by system failures. One issue was uncovered during the MP system testing in August. The data collection electronics were originally designed for the HH sensor and expanded to operate the MP system during construction. The additional cabling and electronics decreased the air circulation and increased the heat loading of the system. Additionally, two DC/DC power supplies in the transmitter circuit were improperly configured such that they operated at a significantly increased temperature. These issues, taken together, lead to transmitter instabilities. Hourly rotation of ice packs placed on the electronics cover alleviated the problem. With the increased data collection tempo for the HH sensor (40 measurements per anomaly, versus 8 for the MP system), the situation was only further aggravated to the point that the ice packs were necessary during the HH

sensor demonstration in October, 2010 where the ambient temperature was only 50 ºF. The ice packs were rotated during data download and battery swap periods, so they did not impact production rates. Since these demonstrations, these issues have been addressed and ice packs are no longer required.

7.6 REMINGTON WOODS SURVEY DATA SUMMARY

7.6.1 Remington Woods, 2008

A simple fiberglass cart carrying four of the MTADS TEM coils was assembled to illustrate the MP system concept at the SERDP/ESTCP/NAOC Technology Transfer Workshop in July of 2008. In October this "pre-prototype" array was tested at DuPont's Remington Woods site in Bridgeport, CT. These tests used the full TEMTADS 5x5 electronics package tethered to a rugged notebook computer to control the MP system. The electronics and batteries were carried in a garden cart (Figure 7-1, left).

Figure 7-1 – Pre-prototype TEMADS MP 2x2 Cart testing at Remington Woods in 2008 (left) and 2009 (right).

Data collection included:

1. Test stand measurements of simulants of the targets of interest (37 mm, 47 mm, 57 mm, 66 mm, 75 mm and 105 mm projectiles),
2. A test field seeded with a variety of ordnance simulants and representative clutter items, and
3. Portions of a 35 acre section of the live site cleanup area.

Results from the test field were mixed. Ten of eleven ordnance items and pipe sections were correctly identified as ordnance. The remaining ordnance-like item (a 1½" diameter by 6" long pipe section) was classified as low confidence clutter on the basis of a poor library match metric, although there was a visual match of the inverted polarizabilities to those for a 47 mm simulant from the test stand measurements. One clutter item (a 4" piece of sheet steel) was incorrectly classified as low confidence ordnance. Thirteen clutter items were correctly classified, but inversions of the data for the remaining nineteen of the forty-four targets in the test field produced unphysical results that could

not be used for classification, and were classified as "can't analyze". Those targets included nails, 50 caliber slugs, "magnetic rocks", wire, small pieces of sheet metal and banding.

Data were collected on 100 anomalies in the live site area before recurrent flat tires on the electronics cart due to punctures by green briar thorns finally called a halt to the operation. On excavation, four of these anomalies were found to be due to ordnance items (intact 37 mm projectiles). These had been classified as high confidence ordnance. Two other anomalies had been classified as low confidence ordnance, but turned out to be a six inch long gate hinge and a piece of chain. Fifteen of the anomalies could not be classified ("can't analyze"). All of the 79 anomalies classified as clutter (3 with high confidence and 76 with low confidence) were found to be clutter items.

Although all of the ordnance items in the live site data had been properly identified, the large fraction (93%) of anomalies that had low confidence or "can't analyze" classifications was disappointing. Realistically, only high confidence clutter anomalies can be left un-dug – three targets out of 100!

Subsequent analysis and testing at Blossom Point revealed that certain target locations and orientations relative to the symmetry planes of the MP system could produce spurious inversion results. In order to feed more information to the inversion we decided to take two measurements over each anomaly – one over the flag and another 20 cm past the flag. Rather than attempt to precisely control the measurement progression, the actual (as opposed to the nominal 20 cm) separation between the measurements was included as another parameter to be determined in the inversion. Controlled tests indicated that this two-step measurement procedure generally produced more consistent inversion results than a single shot over the target.

7.6.2 Remington Woods, 2009

The backpack electronics package for the MP system, which was shared with the MR-200807 hand-held TEM sensor, was completed in 2009. The 2008 pre-prototype array cart, now with the backpack electronics but still controlled using the tethered notebook computer, was again tested at Remington Woods in August, 2009 (Figure 7-1, right).

The munitions cleanup practice at Remington Woods, which has been approved by the EPA for the site, involves an initial EM61-MK2 survey followed by cued ID of potential UXO contacts with a handheld EM61-HH using procedures developed in ESTCP project MR-200108. Roughly one half of the original contacts are typically ruled out as possible UXO items on the basis of their EM61 and/or EM61-HH response characteristics. These are referred to as category 3 contacts. Ten percent of the category 3 contacts are excavated for quality control purposes. For about one third of the initial contacts, factors such as overlapping signatures, weak signal levels, etc. make it impossible to reliably classify the target. These are referred to as category 2 contacts, and all of these are excavated by default. The remaining 15-20% are categorized as potential UXO (category 1 contacts) based on the cued EM61-HH analysis. Typically, only a small fraction of

these are actually UXO. We sampled a selection of category 1, 2 and 3 contacts on a 27½ acre parcel that that had gone through the EM61 survey and EM61-HH cued ID process that summer and was to be dug later that year.

A total of 711 flagged anomalies were interrogated with the MP system using the two-step procedure over the course of 2½ days: 226 category 1 anomalies, 367 category 2's and 117 category 3's. 681 of the anomalies visited with the 2x2 were later excavated, including all of the category 1 and 2 anomalies and 88 of the category 3 anomalies. We used the same three categories (likely UXO, can't tell, likely clutter) to rank the MP system TEM results, and the classification and dig results are summarized in Table 7-17. 23 of the 681 excavated anomalies were due to UXO items (37 mm, 47 mm and 57 mm projectiles), and 528 were due to clutter (including 27 pieces of exploded or broken ordnance items). 130 had no target or were identified as ash or clinker that had been dumped there.

Table 7-17 – Classification and dig results summary for the 2009 Remington Woods test

61HH Category	2x2 Category				Dig Results			
	1	2	3	total	UXO	none*	clutter	total
1	40	102	84	226	17	2	207	226
2	10	326	31	367	6	128	233	367
3	0	69	48	117	0	0	88	88
total	50	497	163	710	23	130	528	681

*includes "ash/clinker"

The principal results of the 2009 Remington Woods test were that the MP system:

1. Correctly re-classified 84 of the 226 EM61-HH category 1 (likely UXO) contacts as clutter.
2. Re-classified a pair of the EM61-HH category 2 (can't tell) contacts which happened to be UXO as category 3 (likely clutter). One was a cluster of three UXO items, the other a single 37 mm projectile.
3. Re-classified a 37 mm projectile as likely UXO that had been "can't tell" with the EM61-HH.
4. Ended up with more category 2 (can't tell) anomalies (497 of 712) than the EM61-HH (367), more than enough to offset the number of clutter items shifted from EM61-HH category 1 to MP system category 3.

All-in-all, the MP system as tested did not perform as well as the EM61-HH cued ID approach that is currently used at Remington Woods. Retrospective analysis indicates that the missed ordnance is more a failing of the classification algorithm than the sensor itself. The real problem is that almost half (171 of 344) of the anomalies that had strong enough response to be classified as ordnance or clutter using the EM61-HH could not be classified using the MP system.

7.7 SPRING VALLEY SURVEY DATA SUMMARY

The pre-prototype MP system, configured as in the 2009 Remington Woods test, was tested at the Dalecarlia Woods site in Spring Valley in May, 2010. 107 flagged anomalies were interrogated in advance of the dig team. Ground truth was later provided for 102 of the targets.

The results were not very informative. 62 of the anomalies had no target or appeared to be magnetic rocks or soil. The remaining 40 anomalies were due to various clutter items (horseshoes, spikes, wire, scrap, etc.). Of these, 27 were found at an offset of more than 40 cm from the flag. No targets of interest (75 mm chemical rounds, 4-in Stokes mortars or Livens projectiles) were found. 82 of the anomalies interrogated with the MP system could either not be analyzed or not be classified. For most of these either there was no target or the target was at the edge of the array. The remaining 25 were correctly classified as clutter. At the time of the demonstration, target locations had only been verified by reacquisition for one of the three grids to be investigated. The flags in the other two grids had not been reacquired as planned. It was later determined that for the positions in the grid that had been reacquired, standard operating procedures on site were not to move the flag to the reacquired position but rather note it in a field log. This was unknown to the field team at the time and the offsets were not provided during the demonstration.

7.8 DATA ANALYSIS IN SUPPORT OF UPGRADING EMI SENSORS TO TRI-AXIAL RECEIVERS FOR 2X2 MP CART SYSTEM

As was seen in earlier Sections, particularly Sections 7.1, 7.6, and 7.7, the performance of the MP system has been disappointing to date. A comparison of results from the Calibration Area at APG is revealing as to why.

Calibration lanes F through K contain six each of 25 mm and 37 mm projectiles, 60 mm and 81 mm mortars, 105 mm HEAT rounds and 105 mm projectiles. The TEMTADS 5x5 array correctly classified 31 of these 36 targets using an automated classification procedure. Of those targets correctly classified by the 5x5, only 17 (55%) were correctly classified by the MP system using a similar procedure. Signal to noise ratios (SNRs) for the MP system and 5x5 array do not appear to be sufficiently different to account for the difference in performance between the two systems. Figure 7-2(a) compares peak signals measured with the MP system with the corresponding peak signals from the 5x5 array for the calibration targets properly classified by the 5x5. The symbols are color coded to indicate MP system classification performance. A solid black symbol means that the target was correctly classified as UXO, and that inversion of the data produced polarizabilities that matched those expected for the target type. Open symbols represent targets that would have been misclassified as clutter. The shaded gray symbols are used for ambiguous results, basically "can't tell". The median of the ratios of MP system peak signal to 5x5 array peak signal is 43%, and there is no significant difference in this ratio between the targets correctly classified by the MP system and the others. While on the calibration grid, RMS noise levels were a bit higher for the 5x5 array than the MP system

(2.57 mV vs. 1.56 mV), so SNR values for the MP system are only slightly smaller (by about 30%) than corresponding SNR values for the 5x5 array. While this may account for some of the performance differential, it seems unlikely that it can account for all, or even most of it. Figure 7-2(b) shows the peak MP system signals as a function of target depth. Symbols are color coded as in Figure 7-2(a). Although targets with the strongest signals tend to be correctly classified while those with the weakest signals tend to be incorrectly classified, there is considerable overlap in the middle. Indeed, median values for the two groups are basically the same (25.0 mV and 25.8 mV, respectively). The main difference is that the deeper targets are the ones more likely to be misclassified. The median depth of the 17 targets correctly classified by the MP system was 32 cm, compared to 53 cm for the other 14.

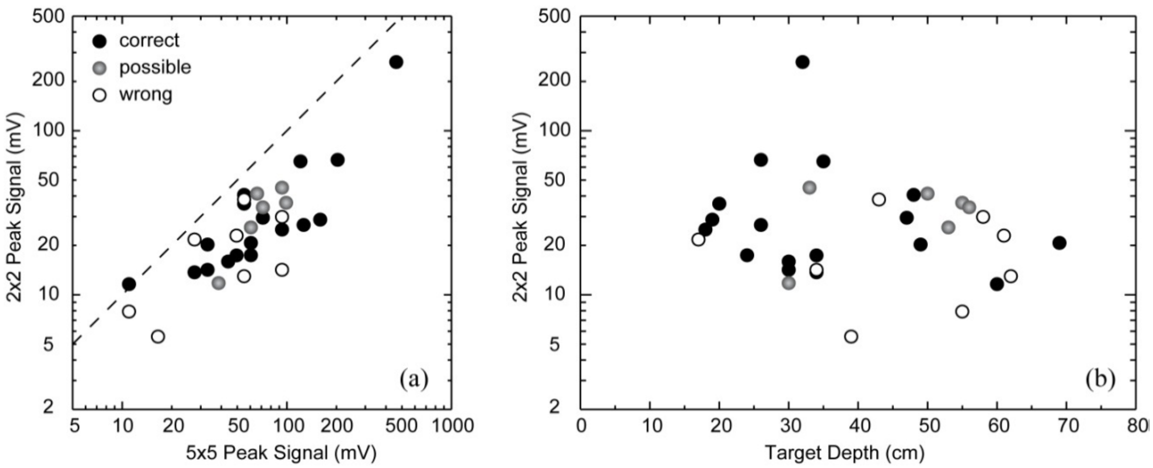


Figure 7-2 – (a) MP system array peak signals vs. 5x5 array peak signals for calibration targets correctly classified by the 5x5 array. Symbol colors indicate MP system classification status. (b) Distribution of MP system peak signals and target depths.

Classification is based on comparing principal axis polarizabilities estimated from data collected over the target with those expected for targets of interest, and good classification performance can only realized only if the polarizabilities can be estimated accurately from the data. We use a standard dipole inversion procedure to estimate the principal axis polarizabilities. This involves searching out the unknown target location, orientation and polarizabilities which minimize the difference between the signal predicted by the dipole model and the measured data. The metric to be minimized is the squared error

$$\epsilon^2 = \frac{(S - S')^2}{S^2}$$

where S is the measured signal vector and S' is the signal vector predicted by the dipole model for a set of signal parameters. How well the parameters can be estimated depends on the noise in the measurements and the shape of the error surface (ϵ^2 as a function of

the target parameters). The error in estimating some parameter ϑ depends on the curvature C of the error surface in the ϑ direction as

$$\delta\vartheta = \frac{\sigma_n}{\sqrt{C}}$$

where σ_n is the RMS noise level normalized by the signal strength as in the equation for ϵ^2. At a given noise level, a sensor which produces an error surface with a sharp minimum is better able to constrain uncertainty in the target parameter than one which has a broad, flat region around the minimum error.

The shape of the error surface depends on both what the sensor is measuring (i.e., the target parameters) and how it is doing the measuring (data density and extent, transmit and receive coil configurations, etc.). Unraveling the various effects can be fairly involved, but a simple example serves to illustrate the basic difference between the MP system (with stepped measurement) and the 5x5 array. Figure 7-3 shows cuts through their error surfaces as functions of horizontal distance from the target location along the minimum curvature direction. All other parameters are fixed at their true values. The target is axially symmetric with 3⅓ to 1 polarizability ratio and is directly under the array, aligned with long axis horizontal and parallel to the cross-track direction (i.e., perpendicular to the 20 cm step for the MP system). The different plots are for different target distances below the sensors as indicated. For a target at 25 cm (on the surface for the MP system, whose sensors ride 27 cm above the ground), the error cuts are similar. For progressively deeper targets the MP system error surface broadens out more and more relative to the error surface for the 5x5 array. The chain-dashed curves show what happens if the standard single axis MP system receiver coils are replaced with three component vector receivers, and we forego the second (stepped) measurement. The additional information from the horizontal components of the induced field at the receivers is able to better constrain the inversion, and the error surface is sharpened significantly for deeper targets.

The pre-prototype MP system has proven to be very well suited for cued identification in areas inaccessible to the vehicle-towed TEMTADS 5x5 array, achieving production rates of 100's of targets per day in challenging environments. However, its classification performance has been disappointing. Too many targets cannot be classified. In order to improve classification performance to levels approaching that of the full TEMTADS 5x5 system we recommended replacing the single axis receive coils in the MP system with tri-axial receiver coils in the final demonstration system. Figure 7-4(a) shows one of the 10 cm square tri-axial receiver cubes used in MetalMapper (MR-200603). The current MP system coil, shown at the right in Figure 7-4(b), is a standard TEMTADS Rx coil wound on a 25 cm square by 8 cm high foam block which is set inside the 35 cm square transmit coil block. The Rx coil is wound tightly at the bottom of the block nearest the ground. The tri-axial cubes used in the MR-201005 man-portable vector sensor are 8 cm square and could easily replace the standard receiver coils using new foam inserts.

The recommendation to replace the sensors in the MP system from the original, single-axis receiver TEMTADS sensors with the tri-axial receiver TEMTADS/3D sensors was made to the ESTCP Program Office in the winter of 2010. The recommendation was approved and the modifications to the system made in early 2011.

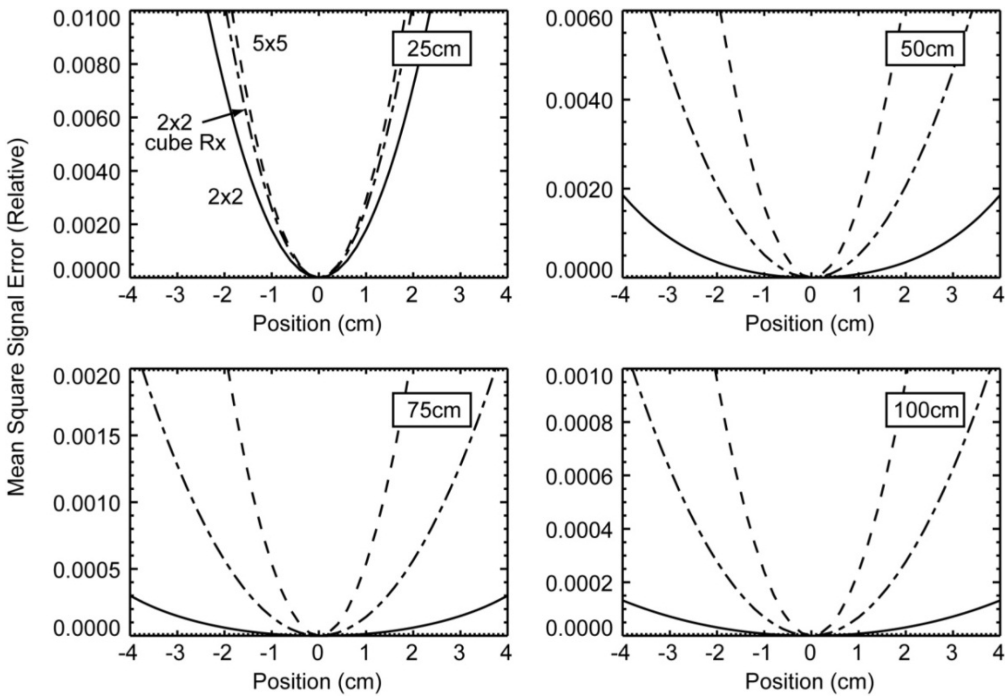


Figure 7-3. Cuts through error surface for 2x2 array (solid lines) and 5x5 array (dashed lines) for targets 25 cm, 50 cm, 75 cm and 100 cm below the array. Chain dashed curves show effects of replacing 2x2 receive coils with tri-axial receiver cubes.

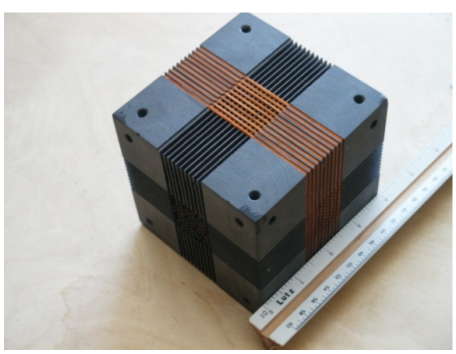
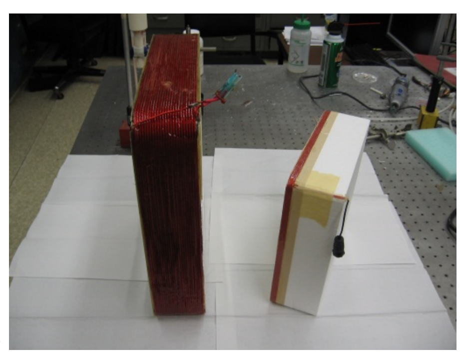
(a)  (b) 

Figure 7-4. (a) MetalMapper tri-axial receiver cube. (b) Standard TEMTADS transmit (left) and receiver (right) coils.

8.0 COST ASSESSMENT

8.1 COST MODEL

The cost elements that were tracked for the APG demonstrations are detailed in Table 9-1 and Table 9-2. The provided cost elements are based on a model recently developed for cost estimation for the MP system at Camp Beale in 2011 [17]. The model assumes a two-person field crew and one data analyst. Production rates from the APG demonstration of these systems were incorporated. Table 9-1 contains the cost model for the HH sensor. Table 9-2 contains the cost model for the MP system. While neither system is currently commercially available, an estimated daily rental rate is provided for comparison to other technologies. The rental rate is based, in part, on the costs of items purchased in prototype quantities (single units) and would presumably decrease significantly if the items were procured at production quantity levels.

8.2 COST DRIVERS

Two factors were expected to be strong drivers of cost for this technology as demonstrated. The first is the number of anomalies which can be surveyed per day. Higher productivity in data collection equates to more anomalies investigated for a given period of time in the field. The time required for analyzing individual anomalies can be significantly higher than for other, more traditional methods and could become a cost driver due to the time involvement. The thoughtful use of available automation techniques for individual anomaly analysis with operator QC support can moderate this effect.

8.3 COST BENEFIT

The main benefit to using a UXO classification process is cost-related. The ability to reduce the number of non-hazardous items that have to be dug or have to be dug as presumptively-hazardous items directly reduces the cost of a remediation effort. The additional information for anomaly classification provided by these sensor systems provides additional information for the purposes of anomaly classification. If there is buy-in from the stakeholders to use these techniques, this information can be used to reduce costs.

9.0 IMPLEMENTATION ISSUES

The goal of these projects was to design and field units more amenable to operation in more confined terrain and topology and smaller tow vehicles / man-portable and handheld operation with the same UXO classification performance as the larger, vehicle-towed NRL TEMADS. A second goal is to transition these technologies from being research prototypes to use in the industrial community where appropriate. The mechanics of collecting classification-grade EMI data with these systems have been shown to be fairly routine in the research community. As part of the 2011 ESTCP Munitions Response Live Site Demonstrations, industrial partners will be exposed to the MP system and the process assessed. Data analysis of data from these systems remains somewhat of a specialty, requiring specific software and knowledge to conduct. The successful transition of the TEMTADS 5x5 array data QC/analysis process to the Geosoft Oasis montaj environment provides a clear pathway for resolving these issues.

Table 9-1 – TEMTADS Hand-Held Sensor Tracked Costs

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	$3,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$9,400 1 8 3 8 $6,000
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$195 3 0.5
Survey Costs	Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$36.90 / anom.** $145 0.2 2 8 0.5
Processing Costs		**$21.65 / anom.**
Preprocessing	Time required to perform standard data clean up and geophysical data QC.	10 min/anom.
Parameter Estimation	Time required to extract parameters for each anomaly.	2 min/anomaly

Table 9-2 – TEMTADS MP 2x2 Cart Tracked Costs

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	 $3,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$12,450 1 16 3 8 $7,250
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$780 3 2
Survey Costs	Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$7.15 / anom.** $190 0.5 2 8 0.5
Processing Costs		**$10.85 / anom.**
Preprocessing	Time required to perform standard data clean up and to merge the location and geophysical data.	3 min/anomaly
Parameter Estimation	Time required to extract parameters for all anomalies.	2 min/anomaly

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